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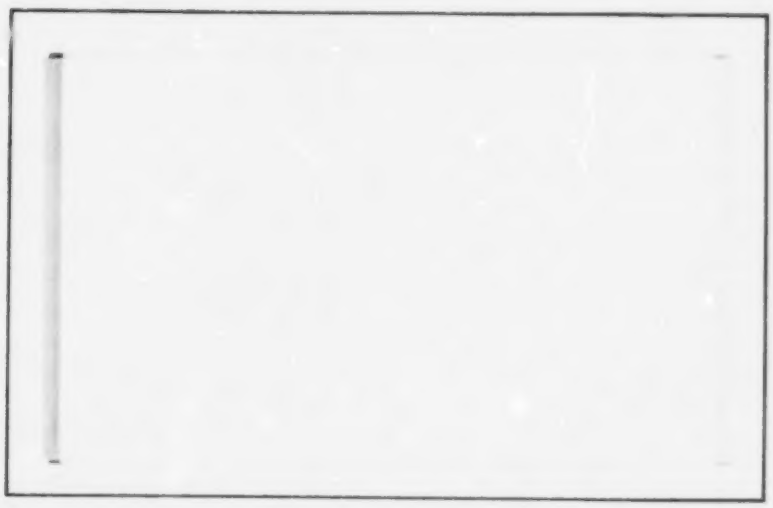

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CONTRACT REPORT NO. OSQ85-00342

FINAL REPORT

PERFORMANCE OF CONCRETE PANELS EXPOSED TO ICE ABRASION AT NANISIVIK, BAFFIN ISLAND

(DSS File No. 03SQ.23440-6-9003)

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October 31, 1986

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MICROMEDIA

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EXECUTIVE SUMMARY

1. CONTRACT OBJECTIVE

The objective of this project (Contract No. DSS 0350-23440-6-9003) was to fabricate twelve reinforced concrete panels of various composition, under controlled conditions, and then install them at an arctic marine location where, over a period of time, the effects of ice abrasion could be determined and studied.

2. RESEARCH SIGNIFICANCE

This project complements previous work, relating to strength development and durability of arctic concretes, undertaken by Prof. Aïtcin at the Université de Sherbrooke for other government agencies. The field measurements will provide, for the first time, important information for the design of offshore platforms and other concrete structures in the Arctic.

3. DESCRIPTION OF CONCRETE PANELS

Twelve panels, each measuring 150 x 300 x 3660 mm, were fabricated using different combinations of cementitious materials and aggregates as shown in Table 1. The panel design has a steel frame to enable longitudinal welding to the vertical sheet-piling of the dock for installation at site. Sets of implanted stainless steel vertical pins will act as datum points for measurement of ice abrasion.

4. CONCRETING MATERIALS AND MIXES

The project provides an opportunity to study, both in the field and in the laboratory, the use of supplementary

cementitious materials with portland cement -- slag, fly ash, condensed silica fume -- for concretes in an arctic marine environment; little is known about the possibilities of lightweight aggregates for northern locations; and even less about fiber concretes.

Except for the DRAMIX steel fibers, all materials were Canadian: the Algoma air-cooled blast furnace slag, the Nova Scotian Lingan fly ash, the SKW Canada condensed silica fume, the Francon-Montreal expanded shale lightweight aggregate and, of course, the normal density aggregates and portland cement and admixtures obtained locally in Sherbrooke.

For comparative purposes all mixes were proportioned to hold constant the absolute volume of cement and supplementary cementitious materials; the volume of fine and coarse aggregates regardless of the type used;and, for the lightweight concretes, the volume of expanded shale was the same as the limestone coarse aggregate of the normal density concretes.

5. LABORATORY TEST PROGRAM

The laboratory test program is detailed in Table 10. Specimens provided information to evaluate, to age 91-days, compressive and flexural strengths, Elastic modulus, air void systems (durability), shrinkage and resistance to abrasion, Tables 2(b) to 2(f). Additional samples were taken for future long-term testing, up to age five years, for strength and resistance to abrasion.

6. EXPOSURE SITE AND INSTALLATION

The panels were fabricated at the University in May,1986, shipped to the site in mid-July and installed during the period August 8 - 11,1986. The project exposure site is the Transport

Canad dock at Nanisivik on Strathcona Sound, Baffin Island, at Latitude 73N. The location for installation of the test panels, Fig.10, was selected to provide good exposure to the ice and ice movement during time of freeze-up yet avoid damage to the panels from ship-loading or other work activities during the summer months. The twelve panels were welded consecutively to the row of sheet piles on the western face of the West caisson of the dock.

All test faces are properly exposed for long-term project study, and concrete surfaces in the areas near the stainless steel datum pins were undisturbed at the time of installation.

7. PHOTOGRAPHIC RECORD

An integral part of this report is the Photographic Appendix which describes visually each step in the development of the project.

8. CONCLUSIONS AND COMMENTS

Strength results of test specimens related well to their mix compositions. As was expected, the steel fiber concretes have greater compressive and flexural strengths than the comparative non-fiber mixes.

In the laboratory results for resistance to abrasion (least weight loss), the top ranking mix was the normal density reference concrete with steel fibers, Table 2(d). The least weight losses were recorded for the fiber concretes, whether for the normal density group or the lightweight mixes. Generally, the normal density concretes performed better than those containing lightweight aggregates.

In the normal density group of concretes, the silica fume and slag mixes did not perform as well as expected. Among the lightweight fiber concretes, the mix containing silica fume and fly ash was slightly better than the plain mix.

Projected on-site studies and measurements of abrasion are essential to relate actual field results to those of the laboratory.

RESUME

1. OBJECTIF DU CONTRAT

Le contrat DSS-0350-23440-6-9003 avait pour objectif de fabriquer douze panneaux de béton ayant des compositions différentes, et de les installer dans l'Arctique canadien afin d'y observer l'action due à l'abrasion des glaces.

2. BUT DE LA RECHERCHE

Ce programme de recherche fait suite à des travaux reliés à la durabilité du béton dans des conditions arctiques déjà effectuées par le Dr Pierre-Claude Aitcin de l'Université de Sherbrooke pour le compte d'agences gouvernementales. Les mesures effectuées sur le terrain vont permettre, pour la première fois, d'apporter des informations importantes sur la conception des plateformes de forage et de toute autre structure en béton devant être construite dans l'Arctique.

3. DESCRIPTION DES PANNEAUX DE BETON

Douze panneaux de béton 150 x 300 x 3 660mm ont été fabriqués à partir des compositions de liants présentés dans le tableau 1. Chaque panneau comportait un cadre en acier lui permettant d'être soudé sur les palplanches du quai. Chaque panneau comporte 6 tiges d'acier inoxydable qui affleurent à la surface ce béton et qui serviront de points de repère pour évaluer l'abrasion du béton.

4. MATERIAUX ET COMPOSITION DES BETONS

On a pu étudier tant en laboratoire qu'en chantier l'effet de différents liants combinés au ciment portland (laitier, cendre volante, fumées de silice) dans un environnement marin. En particulier, très peu de données sont disponibles sur l'utilisation de granulats légers dans l'Arctique, encore moins sur l'utilisation de bétons-fibres dans l'Arctique.

A l'exception des fibres DRAMIX, tous les matériaux qui ont été utilisés dans le projet étaient des matériaux canadiens. Le laitier

provenait des aciéries Algoma, la cendre volante de Nouvelle-Écosse (Lingan), les fumées de silice de la compagnie SKW et les granulats expansés de la compagnie Francon de Montréal. Le sable et le gros granulat ordinaire provenaient de la région de Sherbrooke.

Pour fins de comparaison, tous les mélanges contenaient le même volume de liant, de granulat fin et de gros granulat quelque soit le type utilisé; dans le cas du granulat léger, le volume de schiste expansé était égal à celui du gros granulat de densité ordinaire.

5. PROGRAMME D'ESSAI EN LABORATOIRE

On trouvera dans le tableau 10 le détail des essais en laboratoire. Comme on peut le voir, on a mesuré la résistance en compression et en flexion jusqu'à 91 jours. On a aussi mesuré le module d'élasticité du béton, le facteur d'espacement (durabilité), le retrait et la résistance à l'abrasion (tableaux 2b à 2f). Des échantillons ont aussi été prélevés pour des essais à plus long terme (jusqu'à 5 ans) sur la résistance en compression et à l'abrasion.

6. SITE D'IMPLANTATION ET INSTALLATION

Les panneaux de béton ont été fabriqués en mai 1986 à l'Université de Sherbrooke. Ils ont été expédiés dans l'Arctique par bateau pour être installés sur le quai entre le 8 et le 11 août. Ces panneaux ont été fixés sur le quai de Nanisivik, au nord de l'île de Baffin, dans le fjord Strathcona par 73° de latitude nord environ. L'emplacement des panneaux, figure 10, a été choisi de façon à ce que les panneaux soient bien exposés aux mouvements de la glace tout en évitant qu'ils puissent être endommagés lors de l'accostage des bateaux ou des opérations de chargement de minerai durant les mois d'été. Les douze panneaux ont été soudés à la suite l'un de l'autre sur les palplanches de la face ouest du quai ouest.

Toutes les surfaces de béton sont de la sorte exposées à l'action à long terme des glaces. A la fin des opérations d'installation, on a pu noter que les surfaces de béton au droit des repères en acier inoxydable n'étaient pas endommagées.

7. RECUEIL PHOTOGRAPHIQUE

On pourra retrouver dans le recueil photographique ci-joint en Annexe, une description visuelle de toutes les étapes du projet.

8. CONCLUSIONS

Les résultats obtenus en laboratoire au niveau des résistances mécaniques sont tout à fait conformes aux résultats escomptés. Les bétons contenant des fibres d'acier ont évidemment des résistances en compression et en flexion supérieures à celles des bétons sans fibres. Le béton qui a présenté la meilleure résistance à l'abrasion est le béton ordinaire contenant des fibres d'acier, (tableau 2d). Les pertes de masse les plus faibles furent toujours mesurées dans le cas des bétons fibres. Nous avons pu noter que les bétons fabriqués avec des gros granulats ordinaires performaient mieux que les bétons fabriqués avec des granulats légers.

Dans le cas des bétons de densité normale, les bétons contenant des laitiers et des fumées de silice n'ont pas été aussi performants qu'on aurait pu l'espérer. Par contre, dans le cas des bétons légers, le béton contenant des fumées de silice et des cendres volantes fut légèrement supérieur au béton ordinaire.

Il faudra entreprendre des études à long terme sur le terrain pour essayer d'établir des corrélations entre les résultats obtenus en laboratoire et ceux obtenus sur le terrain.

1. CONTRACT OBJECTIVE

The objective of this project (Contract No. DSS 0350-23440-6-9003) was to fabricate twelve reinforced concrete panels of various composition, under controlled conditions, and install them at an arctic marine location where, over a period of time, the effects of ice abrasion could be determined and studied. Laboratory specimens of the twelve different concretes used in the panels are to be tested to determine physical characteristics.

2. RESEARCH SIGNIFICANCE

This project will complément previous work undertaken by Prof. Aïtcin at the Université de Sherbrooke for other government agencies:

1982 -- Strength Development of Concrete Cured Under Arctic Sea Conditions. DSS Contract No. 17ST.EN 280-1-2669 and 09SU.EN 280-2-3531.

1985 -- Durability of Concrete in the Arctic. National Sciences and Engineering, Research Council of Canada Grant No. A4326.

The field measurements mentioned above will provide, for the first time, important information for the design of offshore platforms and other concrete structures in the Arctic.

3. DESCRIPTION OF CONCRETE PANELS

Twelve panels, each measuring 150 x 300 x 3660 mm, were fabricated using different combinations of cementitious materials and aggregates as shown in Table 1, Description of Materials for Panels. Design details and dimensions are shown in Figs. 1(a) and 1(b). Integrated in the panel is a steel frame of 102 x 102 mm angle that will be welded longitudinally to the vertical sheet-piling of the dock at Nanisivik. The ends of the panels are fitted with steel plates inclined to deflect the vertical thrust of the ice. Reinforcement consisted of three 15M deformed bars (16 mm, diam.) placed longitudinally at 75 mm centres, and three 15M bars placed transversely at a spacing of 915 mm. Also, at the points of transverse reinforce-

ment, stainless steel vertical pins were placed to act as datum points for measurement of ice abrasion.

4. CONCRETING MATERIALS

4.1 Cementitious Materials

4.1.1 Portland Cement

All portland cement used for the project concrete was a Type 10 obtained from the St. Constant Plant of Canada Cement Lafarge. The cement needed for the various mixes required two seperate pallets of 40 sacks each. Since these were delivered seperately the first pallet was used for the normal density aggregate mixes while the second was kept for the series of lightweight concretes. The chemical analysis and physical properties of the first cement delivery only is shown in Table 3. The sample representing the second was misplaced by the cement company and results are unavailable.

4.1.2 Slag

The Algoma air-cooled blast furnace slag was supplied by CANMET. The chemical analysis and physical properties are shown in Table 4.

4.1.3 Fly Ash

The fly ash from Lingan was obtained from Nova Scotia Sand and Gravel. The chemical analysis a nd physical properties are shown in Table 5.

4.1.4 Condensed Silica Fume

The condensed silica fume was supplied by SKW Canada at Becancour. The chemical analysis and physical properties are shown in Table 6.

4.2 Aggregates

4.2.1 Sand

A natural siliceous sand from the Sherbrooke region was the fine aggregate used in all mixes. The physical properties are shown in Table 7. The grading of this sand is well within the specified limits of CSA Std. CAN3-A23.1-M77, as shown in Fig.2(a).

4.2.2 Coarse Aggregate

A metamorphic limestone quarried at Lime Ridge, near Sherbrooke, was the source of coarse aggregate. This material is non-reactive to cement alkalies. The characteristics of three stone sizes used in the normal density mixes are given in Table 8.

Also shown are the proportions to achieve the combined gradings for nominal sizes 14-5 mm and 20-5 mm used in the concretes with and without steel fibers. Previous work had indicated improved workability of steel fiber concretes if the maximum size of aggregates was reduced to 14 mm. The gradings of the three commercial sizes and the combined stone were within the specified limits of CSA Std. CAN3-A23.1 and are shown in Fig.3 and Figs.2(a) and 2(b).

4.2.3 Lightweight Aggregate

An expanded shale supplied by Francon of Montreal was the lightweight aggregate. The physical properties are presented in Table 9 and the grading curve in Fig.4.

4.3 Steel Fibers

The steel fibers used were the DRAMIX product ZP/50.50.

4.4 Admixtures

All twelve concrete mixes utilized admixtures, as shown in Table 2(a), Concrete Mix proportions. These were:

Air Entraining Agent: Conchem MCA, Protex MicroAir, Master Builders*

Water Reducing Agent: PDA 25XL (normal set), Protex

Superplasticizer : Mighty 150, Kao Soap

* Although Conchem MCA was used in all other mixes, it was found that for the slag and steel fiber concrete MicroAir provided the desired air content. (See Section 11.1, Page 8).

5. PRODUCTION OF CONCRETE

5.1 Batching and Mixing

A stationary turbine mixer with a rated capacity of 0.5 m^3 (approximately 1200 kg normal density concrete) was used. Actual total batch weights were 950-1000 kg. The sequence of batching and times of mixing are described below. See Fig. 5.

5.2 Reference Concrete

a)	Mixing of cement and sand	2 minutes
b)	Add batch water (less 5L) and admixtures	1-1½ "
c)	Add coarse aggregate, mix for	5½-6½ "
d)	Check-test for air content and slump	
e)	Add balance of water, mix for	2 "
		Total mixing time 10½-12 minutes

5.3 Concrete with Supplementary Cementing Materials

For mixes using supplementary cementing materials, these were batched with the portland cement.

5.4 Steel Fiber Concrete

The superplasticizer was added at the start of Step 5.2(b). The steel fibers were batched at the end of Step 5.2(b) after the mortar appeared homogeneous. Mixing time was then extended by 1½ min. to increase total mixing time for these concretes to 12 - 13½ minutes. See Figs.6 and 7.

5.5 Lightweight Concrete

The lightweight aggregate was first weighed dry, before 24-hr saturation; then reweighed in the drained condition just prior to batching. This enabled calculation of any water contributed to the mixes by the aggregate. See Fig.6.

6. CONCRETE MIXES

Table 2(a) details the concrete mixes for each of the twelve panels cast. In proportioning, the volume of cementing materials was held constant without regard to aggregates used (normal density or lightweight). This absolute volume of cement and supplementary cementing materials was 127 L/m^3.

In the fiber concretes, the proportions were modified to maintain the same volume of fine and coarse aggregates regardless of the type of aggregate used.

For the lightweight concretes, the volume of the expanded shale aggergate was the same as the limestone coarse aggregate in the normal density concretes.

7. TEST PROGRAM AND RESULTS

7.1 Sampling Program

The sampling program is detailed in Table 10. A total of 63 samples were obtained from each of the twelve concrete batches made. Additionally, slump and standard tests for air content were taken for both normal density and lightweight concretes.

7.2 Fresh Concrete Results

Table 2(b) lists the physical characteristics of the fresh concrete for each of the twelve mixes.

7.3 Hardened Concrete Results

Table 2(b) presents the compressive and flexural strengths of samples tested at ages 1-, 28- and 91-days; Table 2(c) provides data on air contents and bubble spacing; Table 2(d) ranks the mixes in the resistance to abrasion tests and Figs. 8 and 9 show the relative weight losses in those tests;Table 2(e) presents the compressive strength and Elastic Modulus at ages 28- and 91-days; and Table 2(f) shows drying shrinkage at ages 56- and 91-days, after water curing for 7 and 28 days.

8. SHIPMENT OF TEST PANELS TO SITE

Positive identification of each panel was assured, before departure from the laboratory, by numbering them in weld steel on the inclined end-plates.

To protect concrete surfaces from damage during transport and shipping, advantage was taken of the steel panel frames. Pairs of panels were mounted face-to-face, seperated by 3/4" plywood sheet cut slightly larger than the panel widths, and then tightly secured with 1" steel strapping and wood blocks and wedges.

Panels were taken from the University to the Port of Montreal by truck transport several days before sheduled boat shipment in early July. The project exosure site is the dock at Nanisivik on Strathcona Sound, Baffin Island, Northwest Territories, at Latitude 73N. The dock was built by Transport Canada primarily to load zinc and lead ore produced by the nearby mine and mill of Nanisivik Mines Inc.

On arrival, the panels were stored at dockside close by where they were to be installed.

9. INSTALLATION AT DOCKSIDE

The location for installation of the test panels, Fig. 10, was selected to provide good exposure to the ice and ice movement during time of freeze-up yet avoid damage to the panels from ship-loading or other work activities during summer months. The twelve test panels were welded consecutively to the row of sheet piles on the western face of the West Caisson of the dock, during the period August 8 - 11, 1986.

A rubber-tired bulldozer, fitted with a custom-built boom, acted as a forklift to lower and hold in position the panels during welding, as well as place a floating work-platform in the water.

For safety reasons, a steel-angle yoke was fabricated at the subcontractor's machine shop to fit the end assembly of a panel and receive the cable sling attached to the lift boom. This worked well and facilitated the manhandling of the panels.

Test panels were placed in numerical order with Panel No.1 closest to shore. They were positioned vertically so that the top edge of the inclined plate of a panel was flush with the top edge of its sheet pile. They were then tack-welded. This brought the midpoint of a panel approximately halfway between low-water and high-water levels.

Three sets of double-pass welds, at least 300 mm long, were made above low-water level, at midpoint and and above high-water level. A full-width double-pass weld was also placed along the top edge of each panel.

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10. PHOTOGRAPHIC RECORD

The photographic appendix is an integral part of this report and describes visually each step in the development of the project:

-- Laboratory Preparations
-- Casting of Panels and Test Pieces
-- Transportation and Shipping
-- Installation at Site
-- Concrte Surfaces (as installed, August, 1986).

11. PROBLEMS ENCOUNTERED

11.1 Laboratory

Obtaining the desired air content for Batch No.6 presented some difficulty. The addition of normal doses of Conchem MCA to the previous mixes had provided acceptable air contents: Batch No.4 had incorporated steel fibers and a superplasticizer; and Batch No.5 had slag as an ingredient. But when slag, steel fibers and a superplasticizer were used in the same batch it appeared impossible to entrain any air. Only a change to the MicroAir AEA solved the problem.

The most likely hypothesis is that a chemical reaction, between the slag and the soluble glue binding the fibers, produced a destabilizing agent that affected the bubble system of the Conchem MCA air entraining agent. Indeed, the air content immediately following the introduction of the fibers was 3.7%, but two minutes later after thorough dispersion of the fibers, the measured air had fallen to 2% despite two additional doses of the entraining agent.

It was noticed that, with continued mixing, the concrete stiffened as the air content fell. As soon as the MicroAir AEA was introduced the bubble system reappeared and the mix regained workability.

The air content was then measured at 6.4%

This experience indicates the necessity to check the compatibility of the AEA and the fiber-binding glue in concretes utilizing slag, fibers and a superplasticizer. Indeed, with the increased use of multiple admixtures in today's complex concretes, initial small-scale laboratory mixes might avoid problems similar to that mentioned here.

11.2 At Site

Direct welding of panel frames to the sheet piling was found to be impossible in most cases because of slight warping and/or imperfections in the surface planeness of the sheet piles. As many as three pairs of steel plates, 12" x 3" x 5/8", were therefore needed to secure the panel frames.

12. CONCLUSIONS AND COMMENTS

12.1 Strength

In no cases are anomalies to be found: strength results relate well to the mix compositions. The improved compressive and flexural strengths and Elastic Modulus of the steel fiber concretes, when compared to the non-fiber mixes, are not unexpected.

12.2 Resistance to Abrasion

With normal density aggregates the top ranking mix was the reference plus steel fibers. The two non-fiber mixes containing silica fume and slag compared poorly to the reference and fiber concretes. Although the non-fiber reference mix had slightly greater weight loss in the test its performance could be grouped with those of the three fiber mixes.

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There is no clear explanation why the non-fiber silica fume and slag mixes did not perform as well as the non-fiber reference concrete.

With lightweight aggregates the three non-fiber concretes had the greatest weight losses. Of these, the mix with the least loss contained both fly ash and silica fume. The three fiber mixes performed much better; and here again, the best results were given by the mix containing fly ash and silica fume, but only slightly better than the reference lightweight with fibers.

Generally, the normal weight concretes performed better than those containing lightweight aggregates.

12.3 Site Observations (1986)

Despite the several stages of manhandling prior to their final welded position, little damage was experienced by the panels. All test faces are properly exposed for long-term project study, and concrete surfaces in the areas near the stainless steel datum pins were undisturbed at the time of installation. A few minor pock-marks have been recorded in the photographs.

TABLES

Table 1: Description of Materials for Panels.

Panel No.	Cementitious Materials	Aggregates	Type of Concrete
1	Type 10	Normal (20 - 5 mm)	Plain
2	Type 10	Normal (14 - 5 mm)	+ steel fibers
3	Type 10 + 10% silica fume*	Normal (20 - 5 mm)	Plain
4	Type 10 + 10% silica fume	Normal (14 - 5 mm)	+ steel fibers
5	Type 10 + 50% slag	Normal (20 - 5 mm)	Plain
6	Type 10 + 50% slag	Normal (14 - 5 mm)	+ steel fibers
7	Type 10 + 20% fly ash	Lightweight C.A. Natural Sand	Plain
8	Type 10 + 20% fly ash	Lightweight C.A. Natural Sand	+ steel fibers
9	Type 10	Lightweight C.A. Natural Sand	Plain
10	Type 10	Lightweight C.A. Natural Sand	+ steel fibers
11	Type 10 + 10% silica fume + 20% fly ash	Lightweight C.A. Natural Sand	Plain
12	Type 10 + 10% silica fume + 20% fly ash	Lightweight C.A. Natural Sand	+ steel fibers

* Volume replacement of portland cement

** Lightweight coarse aggregate, 14 - 5 mm.

Materials		Mixes Normal Density Aggregates						Mixes Lightweight Aggregates					
		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
Water		159	157	153	153	156	158	142	140	147	156	139	138
Cement Type 10		398	395	355	354	203	199	315	310	390	386	272	269
Silica Fume		-	-	28	28	-	-	-	-	-	-	28	27
Fly Ash		-	-	-	-	-	-	70	69	-	-	69	68
Slag		-	-	-	-	183	179	-	-	-	-	-	-
Steel Fibers		-	49	-	49	-	50	-	48	-	48	-	48
Sand (SSD)		696	841	704	849	732	862	727	850	733	840	729	842
Normal Aggregates	10 mm	314	556	312	562	320	571	-	-	-	-	-	-
	14 mm	522	301	520	302	533	307	-	-	-	-	-	-
	20 mm	209	-	208	-	212	-	-	-	-	-	-	-
	Total	1045	857	1040	864	1065	878	-	-	-	-	-	-
Lightweight Aggregate		-	-	-	-	-	-	689	577	682	568	679	573
Air entraining Agent (mL/100 kg)		55	18	84	19	30	350 *	29	15	17	18	46	28
Water Reducer (mL/100 kg)		304	298	287	304	302	300	291	308	286	303	293	300
Superplasticizer (L/m^3)		-	1.84	1.03	2.97	-	3.28	-	0.14	-	1.52	-	0.6

Table 2 (a) - Concrete Mix Proportions
* 125 mL Micro-Air and 225 mL Conchem MCA

Concrete Properties			Mixes Normal Density Aggregates						Mixes Lightweight Aggregates					
			#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12
FRESH CONCRETE	Ratio W/Cimentious		0.40	0.40	0.40	0.40	0.40	0.42	0.37	0.37	0.39	0.40	0.38	0.39
	Slump (mm)		75	80	105	95	60	110	80	40	55	55	30	65
	Air (%)		6.8	7.4	7.6	6.8	5.4	6.4	6.0	7.1	4.6	5.2	5.5	8.0
	Unit Weight (kg/m^3)		2298	2298	2277	2298	2340	2326	1943	1995	1950	1995	1915	1965
COMPRESSIVE STRENGTH (MPa)	1d	100x200mm	20.0	21.4	19.6	19.0	10.0	6.5	12.9	12.9	21.4	24.0	13.5	12.5
		150x300mm	20.2	20.6	18.6	20.1	10.2	6.6	12.6	12.7	20.3	22.9	13.2	12.3
	28d	100x200mm	41,6	42,4	43,6	53,1	55,6	54,7	36,9	38,4	43,5	45,2	42,1	40,1
		150x300mm	38,1	41,6	41,8	49,4	51,2	51,6	34,5	37,0	40,8	41,8	38,6	42,5
	91d	100x200mm	43.8	50.6	48.0	59.0	56.5	60.7	44.3	45.0	47.4	47.1	47.6	49.8
		150x300mm	-	-	-	-	-	-	-	-	-	-	-	-
	1year	100x200mm												
		150x300mm												
FLEXURAL STRENGTH (MPa)	28d	100x100 x 400 (mm)	5,7	6.0*	7.2**	5,6	6.8	7.7	7,2	7.9	8.2	4,4	4.8	5.5	5,0	5.5	8.7	4,8	5.4	7.0
	91d	100x100 x 400 (mm)	5.9	6.5	6.6	6.1	7.3	7.5	7.4	8.1	8.6	4.9	5.4	6.0	5.2	5.6	6.2	4.8	5.8	7.6
	x year	100x100 x 400 (mm)																		

Table 2 (b) - Physical Properties of Fresh and Hardened Concretes

* First crack ** Rupture

Mix Identification			Air Content		D. av. (μm)	Alpha (mm^{-1})	L (μm)
			Fresh %	Hardened (%)			
Normal Weight Coarse Aggregate	1	Reference	6.8	6.1	142	42.3	95
	2	Reference + Fibers	7.4	4.5	159	38.7	130
	3	10% Silica Fume	7.6	6.6	111	54.4	75
	4	10% Silica Fume + Fibers	6.8	5.2	192	31.6	150
	5	50% Slag	5.4	4.5	116	52.7	100
	6	50% Slag + Fibers	6.4	5.4	222	27.2	180
Light Weigth Coarse Aggregate	7	Fly Ash 20%	6.0	4.9	152	39.4	125
	8	Fly Ash 20% + Fibers	7.1	5.8	166	36.4	115
	9	Reference	4.6	4.5	177	33.9	150
	10	Reference + Fibers	5.2	4.0	171	35.0	140
	11	Fly Ash 20% + Silica Fume 10%	5.5	6.4	136	44.0	95
	12	Fly Ash 20% + Silica Fume 10% + fibers	8.0	7.6	164	36.8	95

Table 2(c) - Air Contents and Bubble Spacing

Rank	Mix/Panel Number	Composition of Mix	Weight Loss %
1	2	Reference, normal weight, + fibers	0.86
2	6	Slag 50%, normal weight + fibers	0.96
3	4	Normal weight + silica fume, + fibers	1.06
4	1	Reference, normal weight	1.09
5	12	Lightweight, + fly ash + sil. fume + fibers	1.57
6	10	Lightweight + fibers	1.60
7	3	Normal Wt. + silica fume	1.68
8	5	Normal Wt. + Slag	1.75
9	8	Fly Ash, lightweight + fibers	1.75
10	11	Fly Ash, + silica fume, lightweight	1.91
11	9	Lightweight	2.24
12	7	Lightweight + Fly Ash	2.44

Table 2(d) - Classification of Concretes According to Weight Loss.

	Concrete Mixes	Age (d)	Compressive Strength (MPa) 100 x 200 mm	Elastic Modulus (GPa)
NORMAL WEIGHT AGGREGATES	# 1 Type 10 Plain	28	41.6	31.9
		91	43.8	32.6
	# 2 Type 10 Steel fibers	28	42.4	29.2
		91	50.6	34.9
	# 3 Type 10 + S.F. Plain	28	43.6	30.7
		91	48.0	33.1
	# 4 Type 10 + S.F. Steel fibers	28	53.1	30.8
		91	59.0	35.3
	# 5 Type 10 + Slag Plain	28	55.6	36.2
		91	56.5	35.9
	# 6 Type 10 + Slag Steel fibers	28	54.7	33.8
		91	60.7	38.1
LIGHTWEIGHT AGGREGATES	# 7 Type 10 + F.A. Plain	28	36.9	21.5
		91	44.3	23.9
	# 8 Type 10 + F.A. Steel fibers	28	38.4	22.6
		91	45.0	23.2
	# 9 Type 10 Plain	28	43.5	22.2
		91	47.4	23.0
	#10 Type 10 Steel fibers	28	45.2	22.8
		91	47.1	24.7
	#11 Type 10 + F.A. + S.F. Plain	28	42.1	21.7
		91	47.6	23.2
	#12 Type 10 + F.A. + S.F. Steel fibers	28	40.1	23.2
		91	49.8	23.2

Table 2(e) - Compressive Strength and Elastic Modulus at Ages 28 and 91 days.

S.F. = Silica Fume
F.A. = Fly Ash

	Concrete Mixes	Drying Shrinkage (μm/m)							
		Water cured for 7 d then air dried up to 1 year				Water cured for 28 d then air dried up to 1 year			
		Age				Age			
		56 d	91 d	180 d	1 year	56 d	91 d	180 d	1 year
NORMAL WEIGHT AGGREGATES	# 1 Type 10 Plain	- 379	-522			-228	-397		
	# 2 Type 10 Steel fibers	- 478	-577			-283	-412		
	# 3 Type 10 +S.F. Plain	-427	-511			-191	-320		
	# 4 Type 10 +S.F. Steel fibers	-397	-449			-195	-294		
	# 5 Type 10 +Slag Plain	-265	-349			-136	-254		
	# 6 Type 10+Slag Steel fibers	-335	-426			-162	-290		
LIGHTWEIGHT AGGREGATES	# 7 Type 10+F.A. Plain	-452	-603			-228	-460		
	# 8 Type 10+F.A. Steel fibers	-515	-647			-265	-500		
	# 9 Type 10 Plain	-419	-585			-224	-452		
	# 10 Type 10 Steel fibers	-500	658			-276	-515		
	# 11 Type 10+F.A. + S.F. Plain	-371	-518			- 96	-254		
	# 12 Type 10+F.A. + S.F. Steel fibers	-489	-570			-154	-312		

Table 2(f) - Drying Shrinkage at 56 and 91 Days, AfterWater Curing.

Table 3 - Chemical Composition and Physical Properties of Cement, Normal Density Concretes.

Chemical Composition

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	L.O.I.
20,8	4,0	3,1	62,1	2,8	0,22	0,93	3,4	1,9

Bogue Composition

C_3S	C_2S	C_3A	C_4AF
50,8	21,4	6,5	9,4

Fineness, Spec. Surface	410 m^2/kg
Percentage passing 74 µm sieve	85,9%
Time of setting, initial	140 min
Time of setting, final	240 min
Compressive strength	1 d 22,5 MPa
	7 d 27,6 MPa
	28 d 34,8 MPa

Table 4 - Chemical Composition and Physical Properties of Slag

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	L.O.I.
38,0	8,2	0,8	33,0	15,3	0,4	0,6	3,1	-0,7*

* gain

Percentage passing 74 µm sieve	99,6%
Fineness, Blaine	520 m^2/kg

Table 5 - Chemical Composition and Physical Properties of Lingan Fly Ash. *

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	SO_3	L.O.I.
39,5	21,7	27,8	1,4	1,8	0,6	2,1	1,1	2,2

Percentage passing 74 µm sieve	97 %
Fineness, Blaine	468 m^2/kg
$SiO_2 - Al_2O_3 - Fe_2O_3$ =	89 %

* Class F fly ash.

Table 6 - Chemical Composition and Physical Properties of Condensed Silica Fume

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	L.O.I.
91.8	0.4	1.7	0.5	0.3	0.1	1.3	3,5

Specific Surface, nitrogen absorption 20 m^2/kg

Note: The silica fume, as batched, contained some moisture. This was checked for each mix and varied from 14.5 - 15.5%.

Table 7 - Physical Properties of Sand

(Aimé Côté)

d_{ssd} = 2.6	Absorption= 1.4%	F.M.= 2.50
Colour Index: 1		

Sieve Size	Total Percentage Passing
100 mm	100
5 mm	96
2,5 mm	85
1,25mm	74
630 µm	58
315 µm	32
160 µm	6

Table 8 - Physical Properties of Coarse Aggregate (Lime Ridge)

	Commercial Sizes		
	20 mm	14 mm	10 mm
d_{ssd}	2.70	2.70	2.70
Absorption, %	0.4	0.6	0.6
Mix proportion, % Normal Concretes	20	50	30
Mix proportion, % Steel Fiber Concrete	0	35	65
ρ_{ssd}, combined (20-5 mm)	1595 kg/m^3		

GRADING

Sieve Size	Total percentage passing		
	20 mm	14 mm	10 mm
28 mm	100	100	100
20 mm	84	100	100
14 mm	21	71	100
10 mm	8	27	100
5 mm	3	6	11
2,5 mm	2	4	2

Table 9 - Properties of Lightweight Aggregate (expanded shale)

d_{ssd}= 1.80
Absorption (24 hr)= 10.1%
ρ dry = 1 100 kg/m^3

GRADING

Sieve Size	Percentage passing
20 mm	100
14 mm	98
10 mm	79
5 mm	16
2,5 mm	8

TYPE OF TEST		SPECIMEN SIZE	TEST AGE																	NUMBER OF SAMPLES
			DAYS												YEARS					
			1	3	7	11	14	21	28	32	35	42	56	91	180	1	2	3	4	5	
COMPRESSION STRENGTH		100x200 mm	3						3					3		3	3	3	3	3	24
		150x300 mm	3						3					-		3	-	-	-	-	9
FLEXURAL STRENGTH		100x100x400 mm							3					3		3		3		3	15
ELASTIC MODULUS		150x300 mm							2					2							4
ABRASION		150x300 mm							2							2					4
L		100x100x400 mm												1							1
SHRINKAGE	Water	100x100x375 mm	2	X	X	X	X	X			X			X	X	X					2
	Air (7d)	100x100x375 mm			2	X	X	X			X			X	X	X					2
	Air (28d)	100x100x375 mm							2	X	X	X	X	X	X	X					2
																				TOTAL:	63

Table 10 - Sampling Program, per Batch

FIGURES

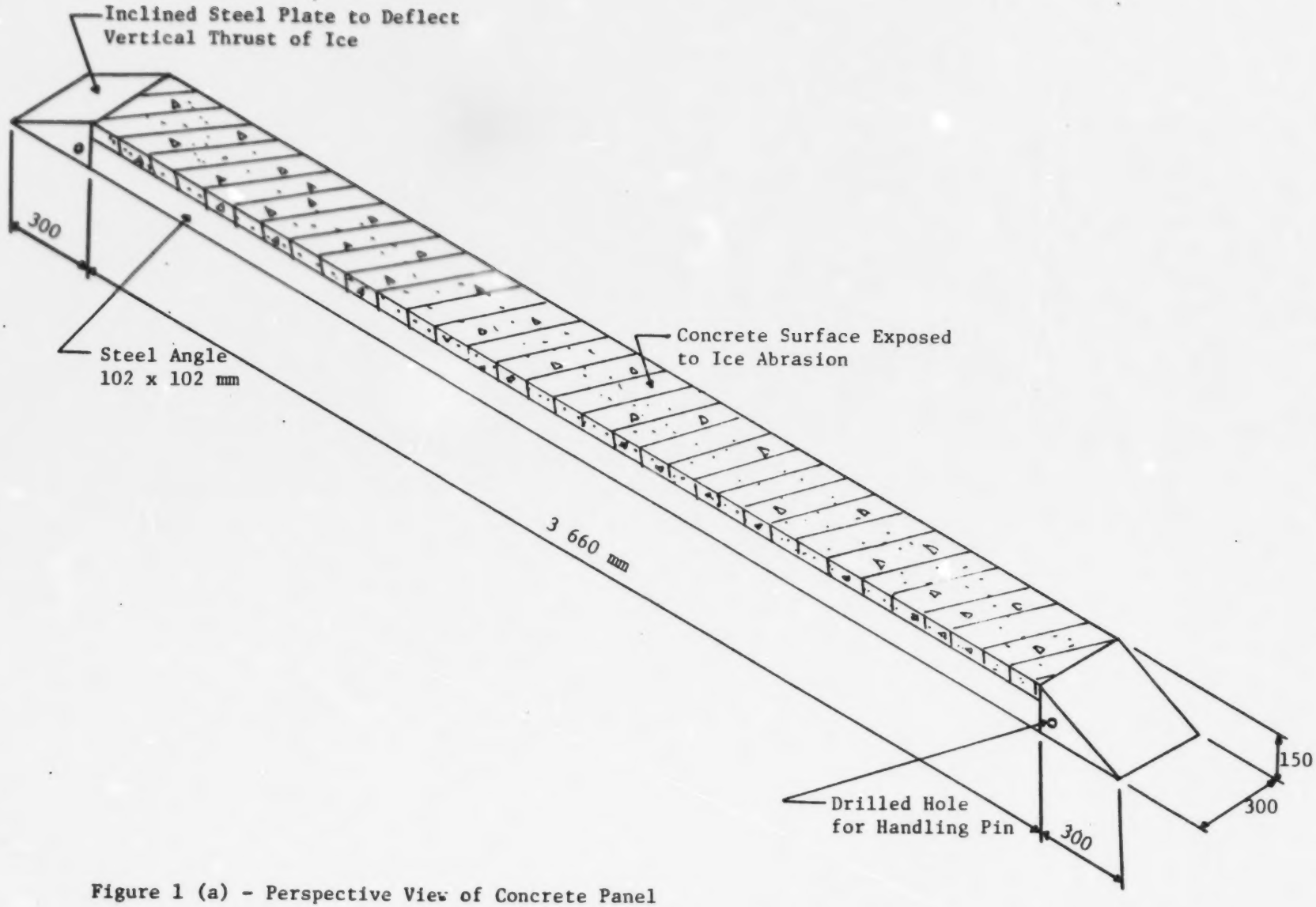
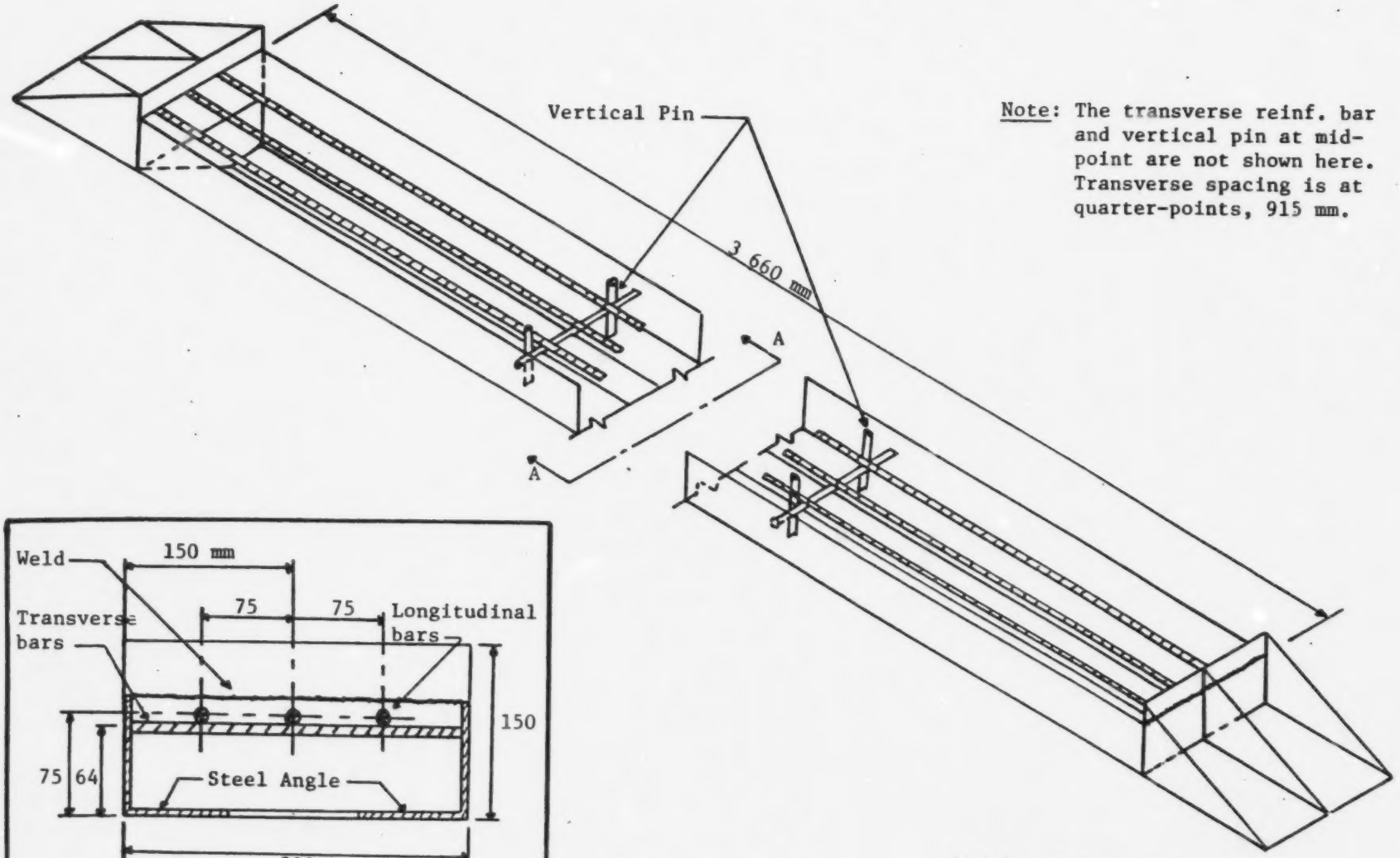


Figure 1 (a) - Perspective View of Concrete Panel



Note: The transverse reinf. bar and vertical pin at mid-point are not shown here. Transverse spacing is at quarter-points, 915 mm.

Weight of Steel Frame and Reinforcement: 100 kg

Figure 1 (b) - Perspective View of Steel Frame and Reinforcement of Concrete Panel

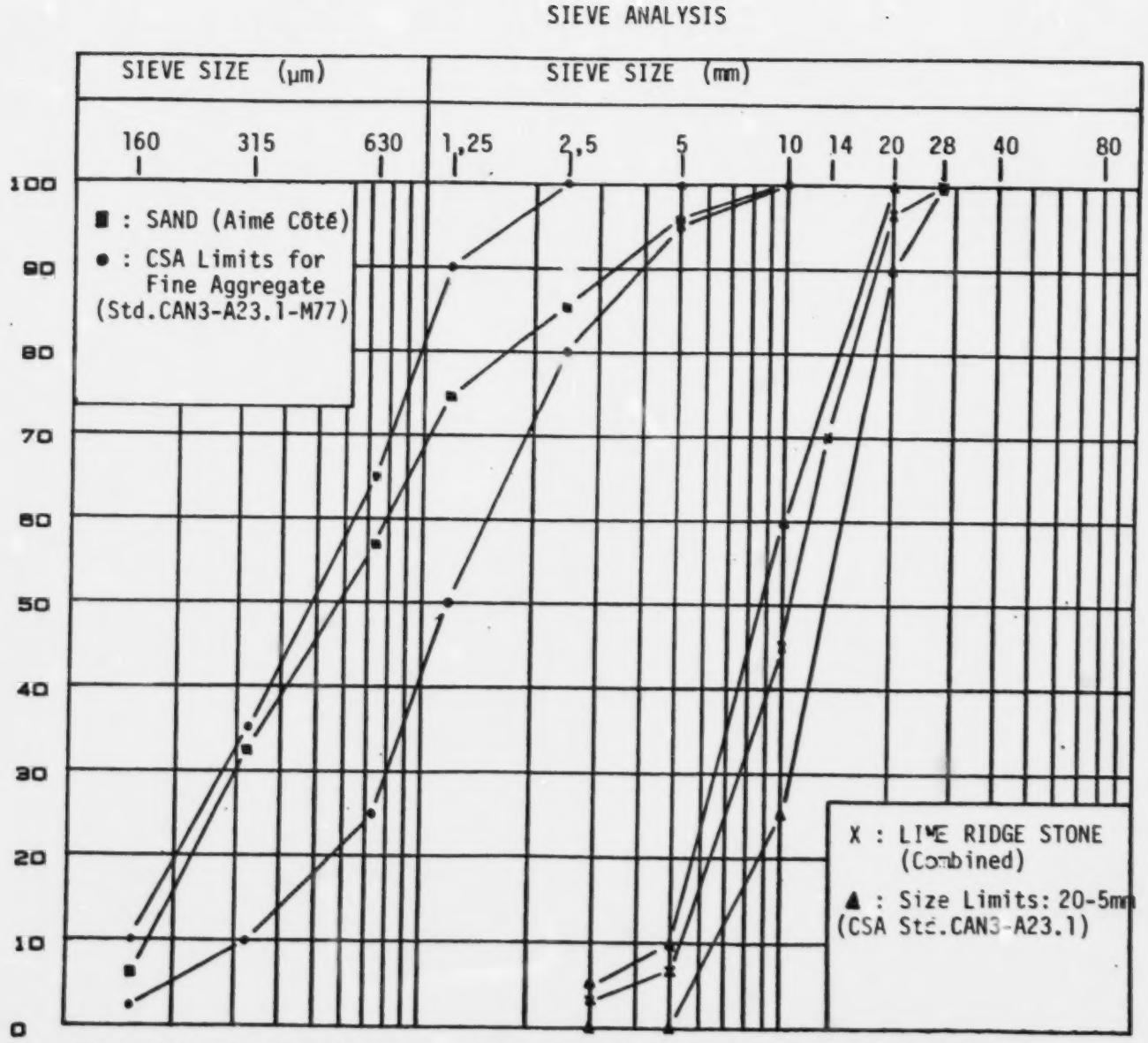


Fig 2 (a): Grading Curves for Sand and Combined Coarse Aggregate, 20-5mm

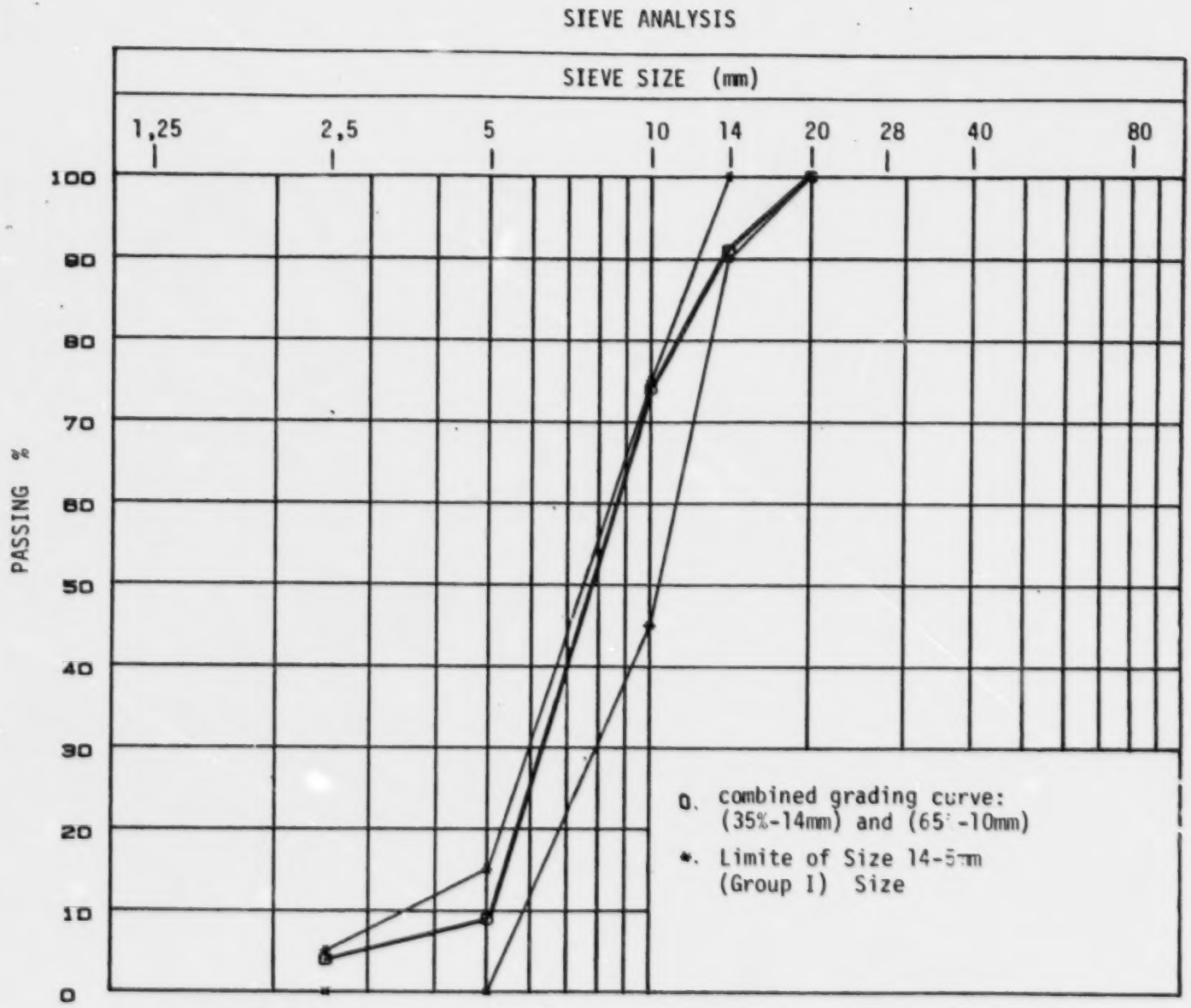


Fig 2 (b): Groding curve for Combined Normal Density Coarse Aggregate, 14-5 mm size, for Steel Fiber Concrete

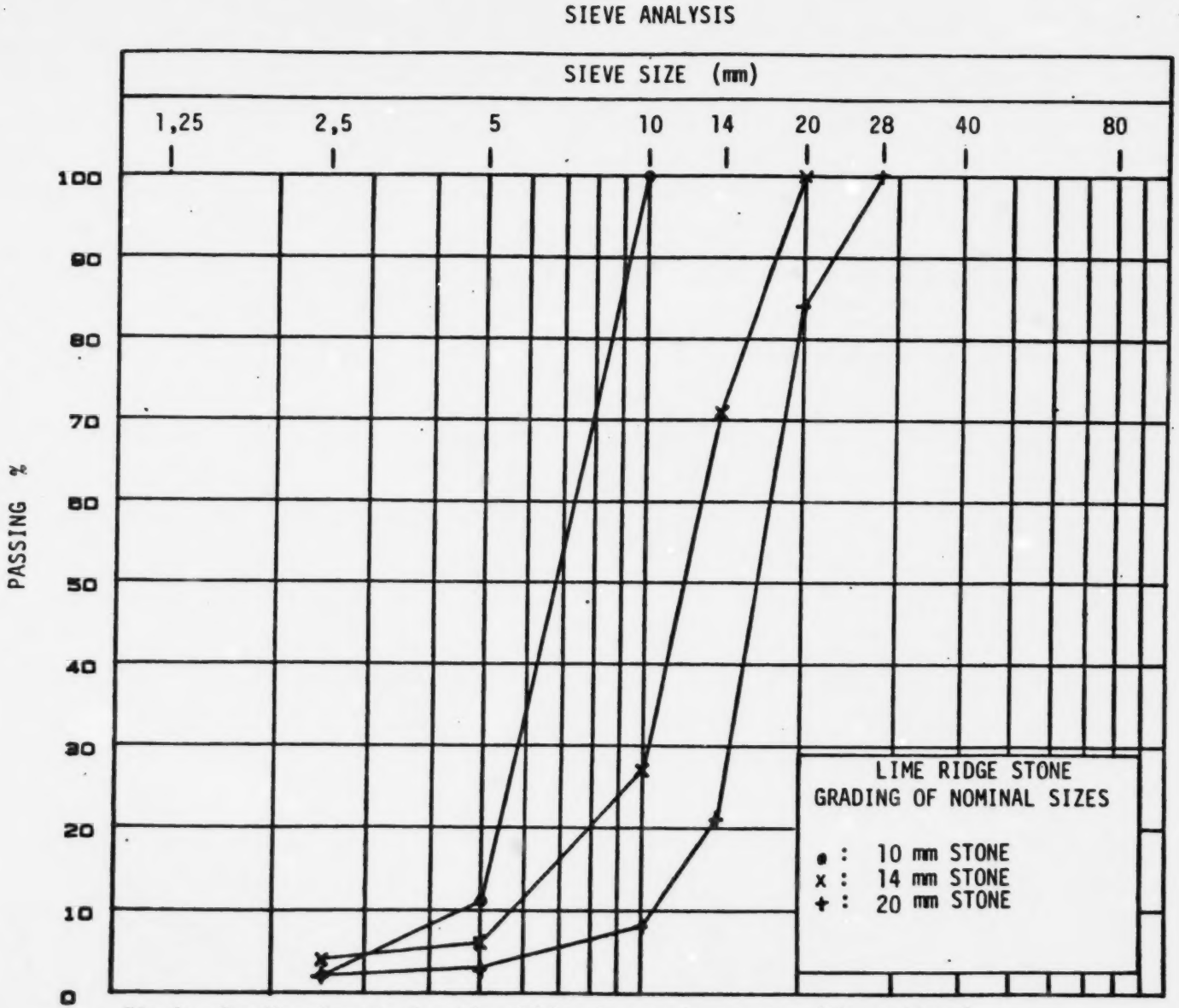


Fig 3: Grading Curves for Lime Ridge Coarse Aggregate (Three Sizes)

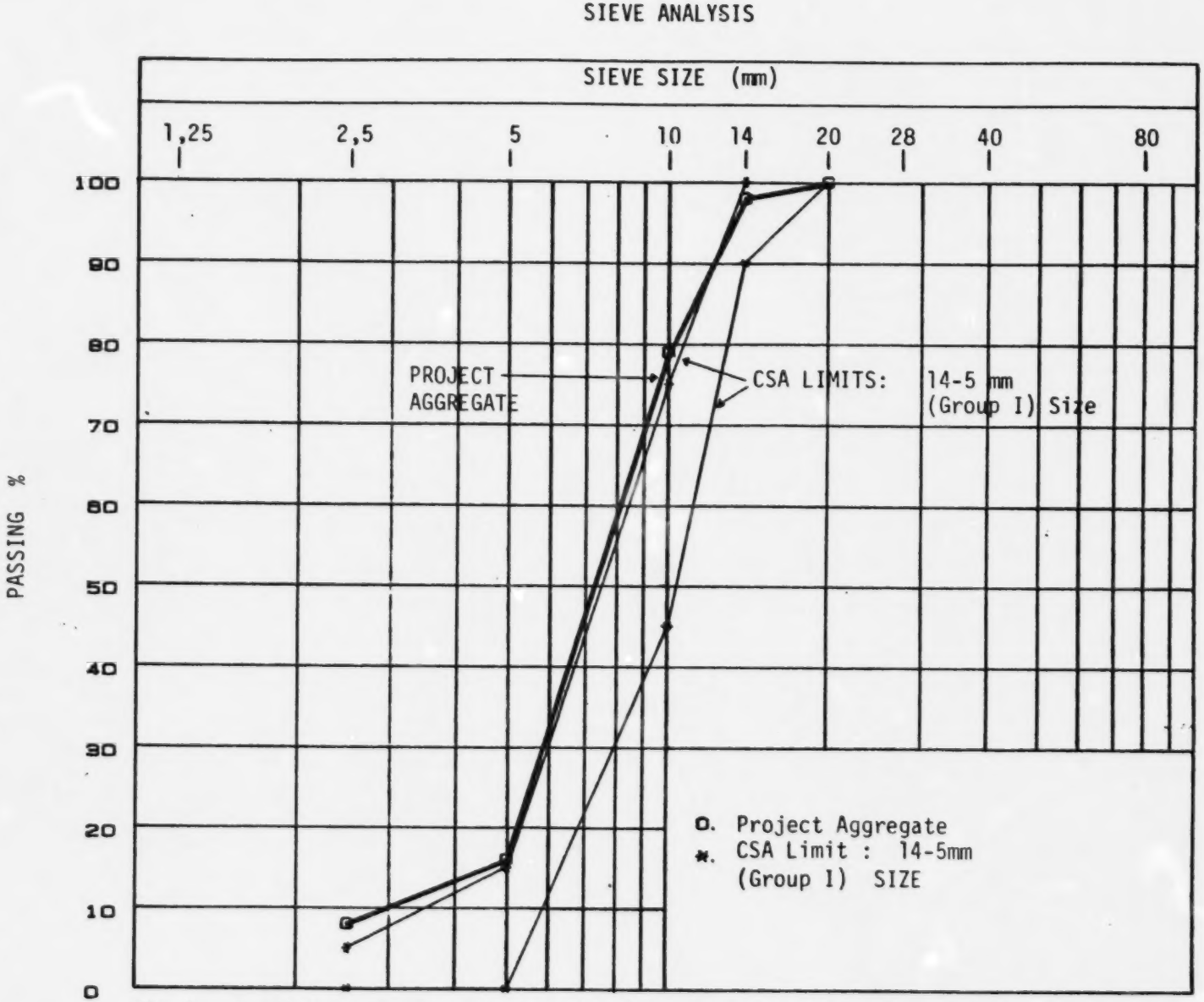


Fig 4: Grading Curve of Project Lightweight Aggregate (Expanded Shale)

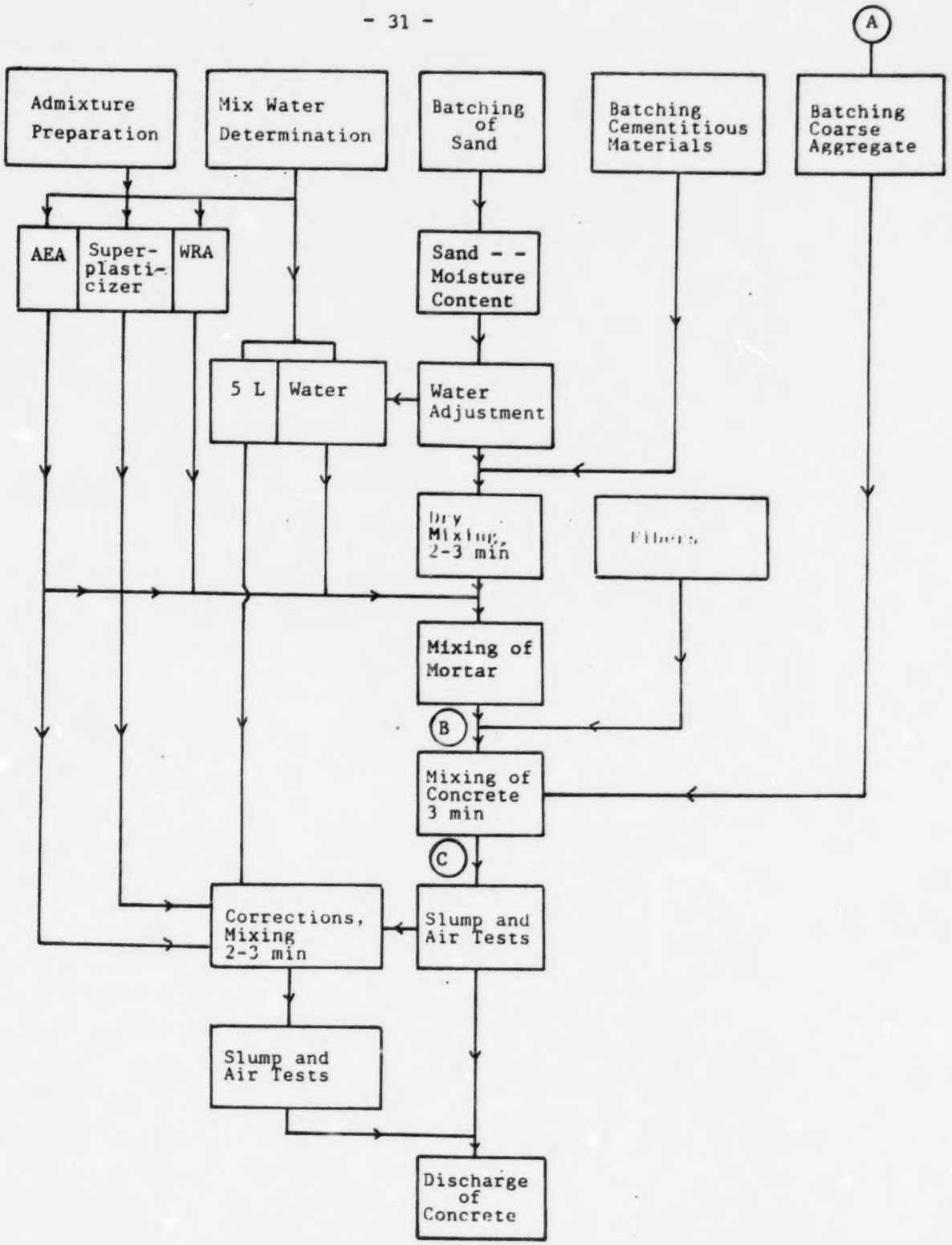


Fig.5 - Flow Diagram: Batching and Mixing of Normal Density Concrete

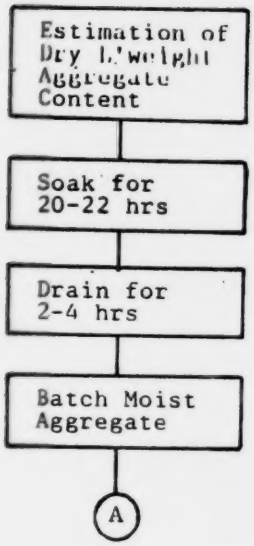


Fig.6 - Preparation of Lightweight Coarse Aggregate

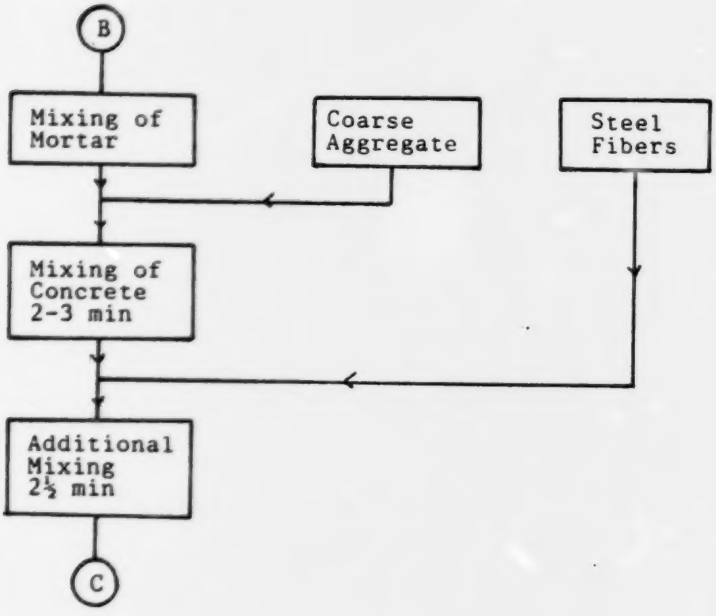


Fig.7 - Flow Diagram: Mix Procedure for Lightweight Steel Fiber Concrete

NORMAL WEIGHT AGGREGATES

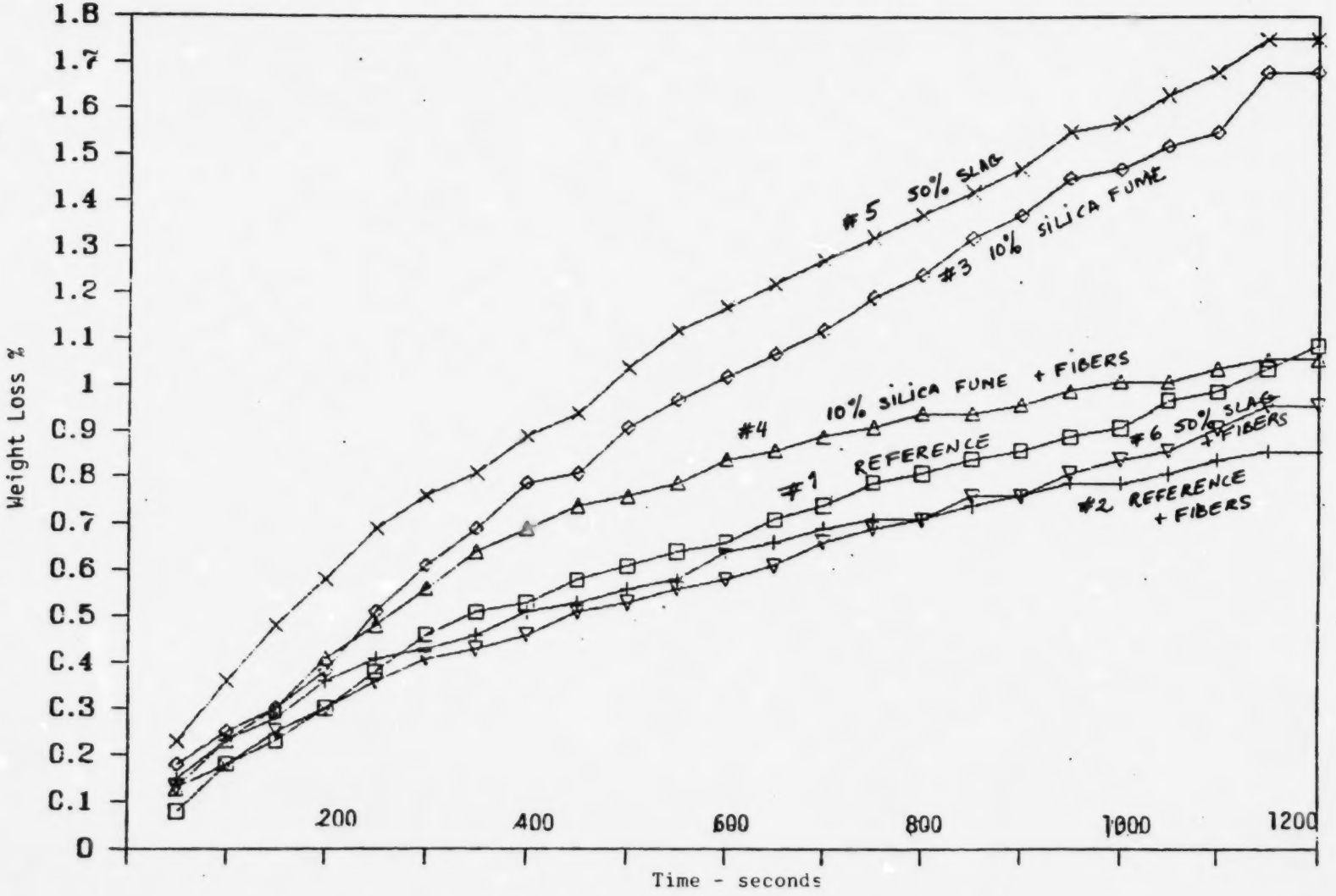


Figure 8 - Resistance to Abrasion, Normal Weight Concrete.

LIGHTWEIGHT AGGREGATES

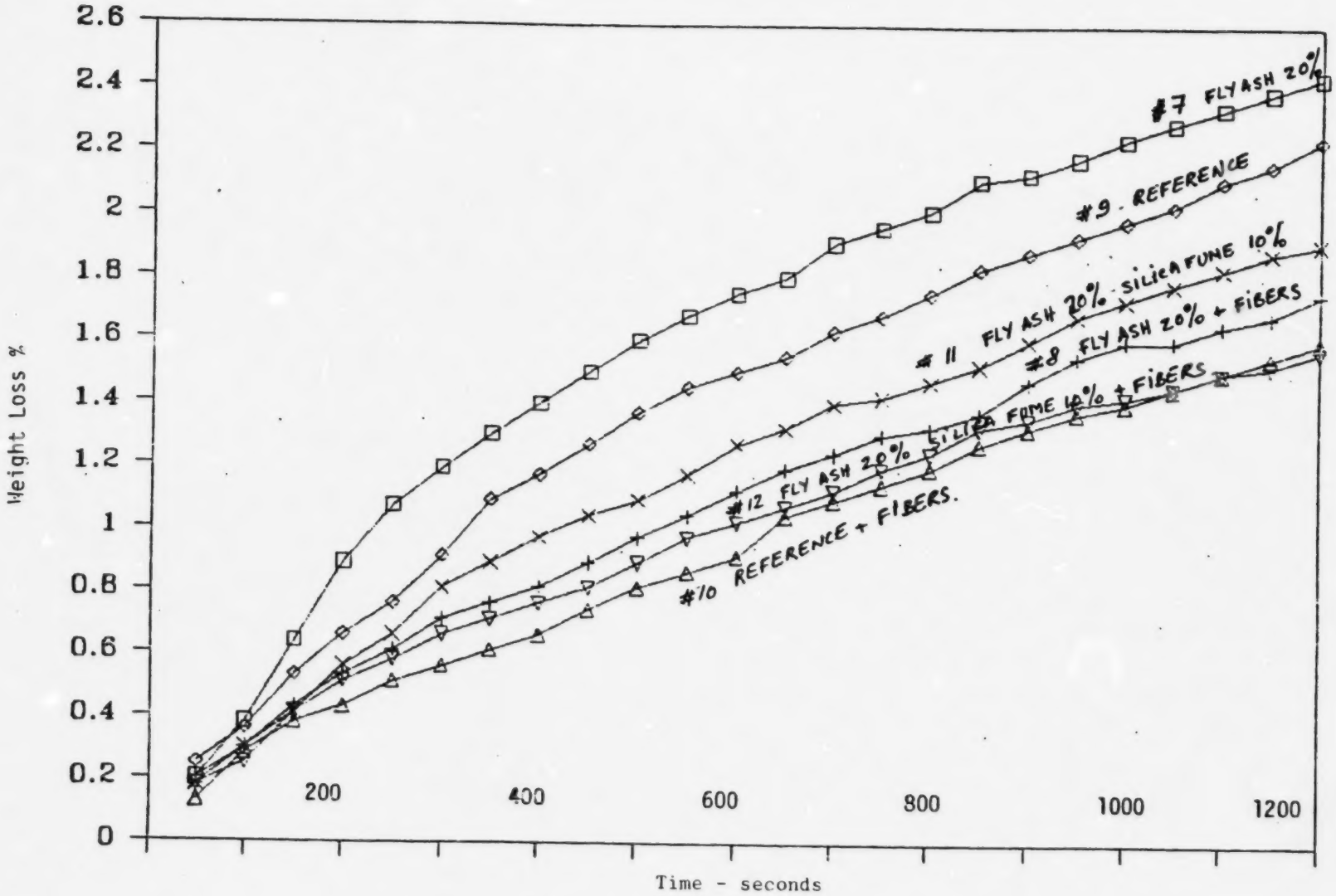


Figure 9 - Resistance to Abrasion, Lightweight Concrete.

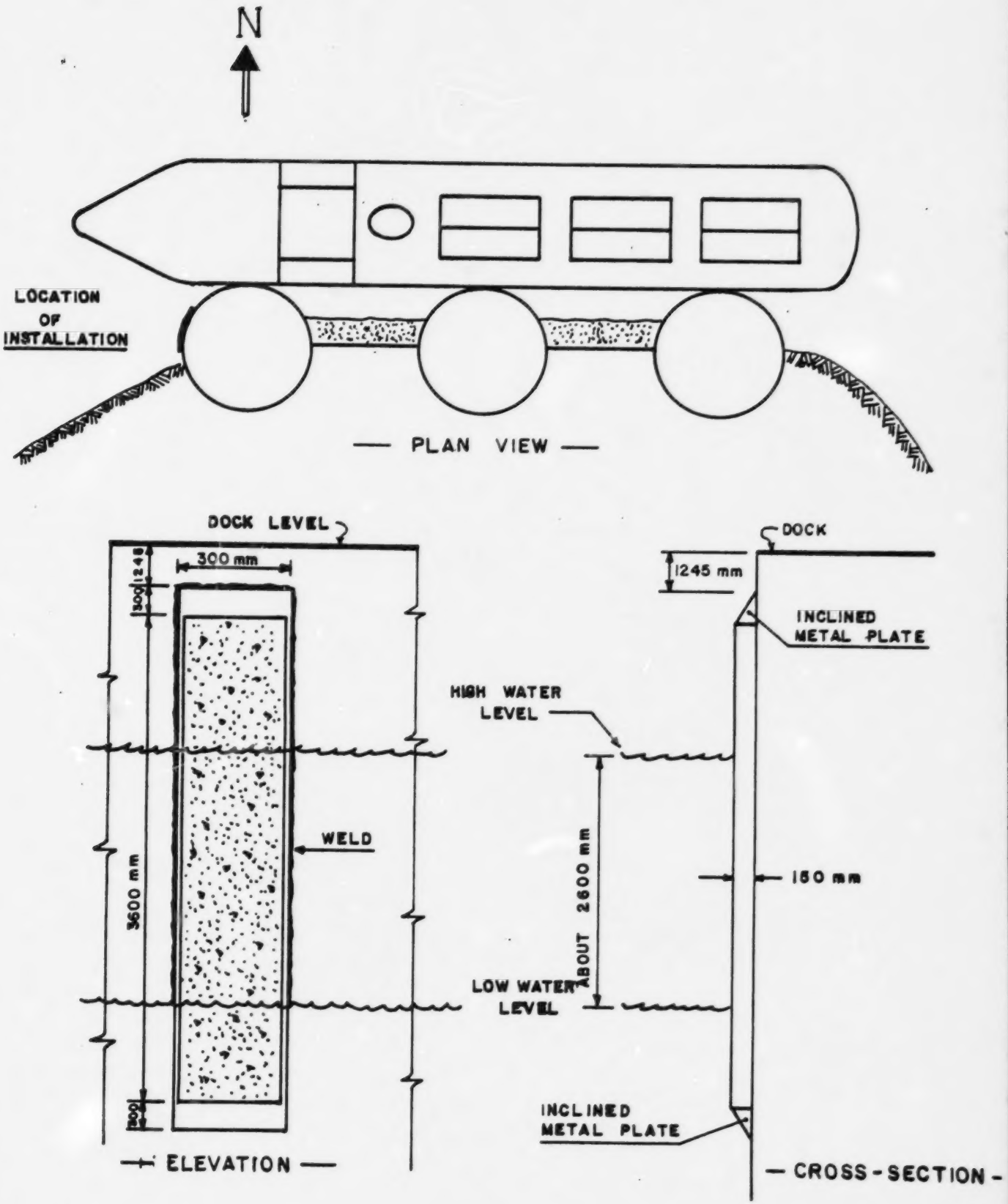
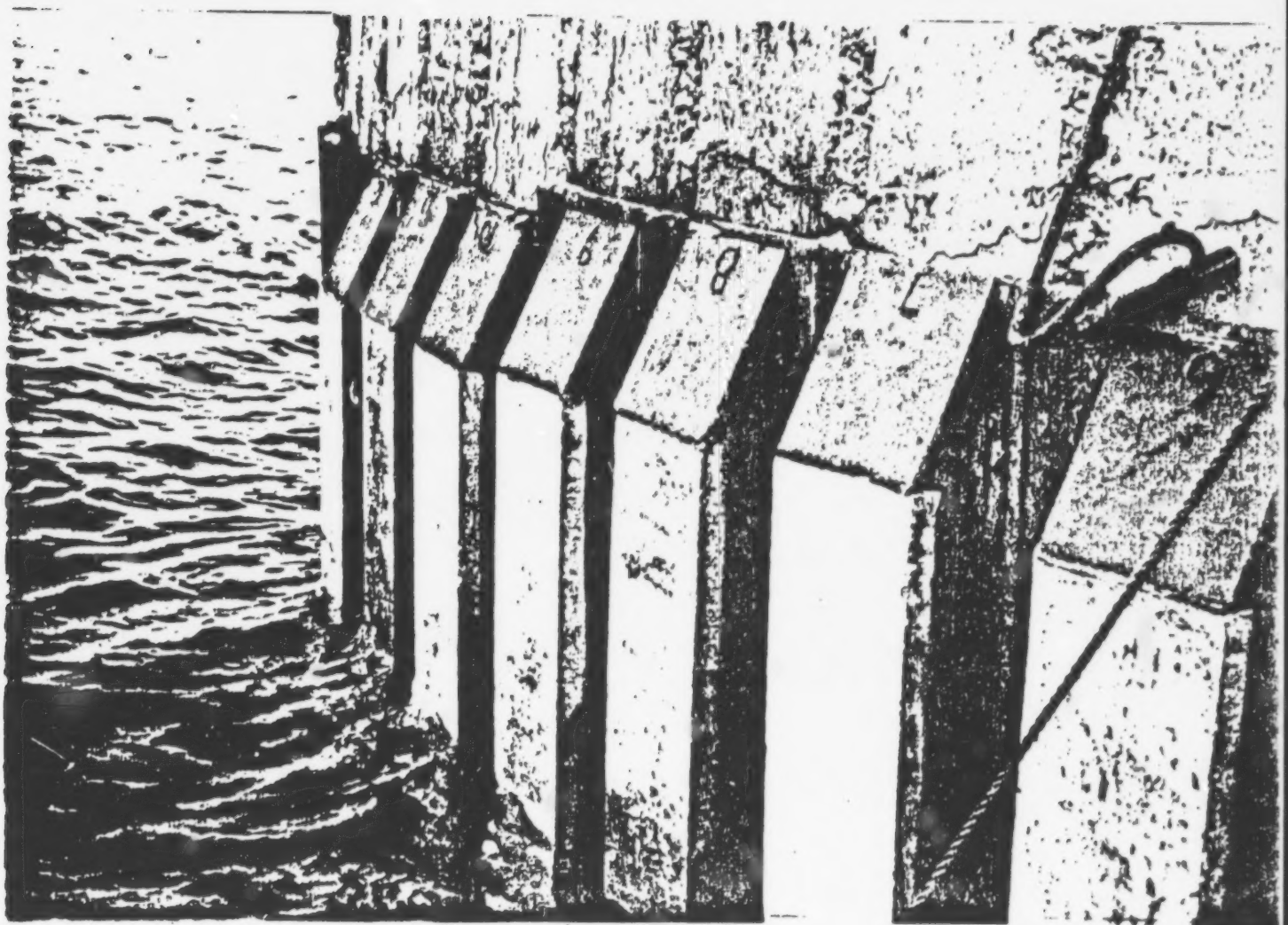


FIGURE 10 PANEL INSTALLATION DETAIL

PHOTOGRAPHIC APPENDIX

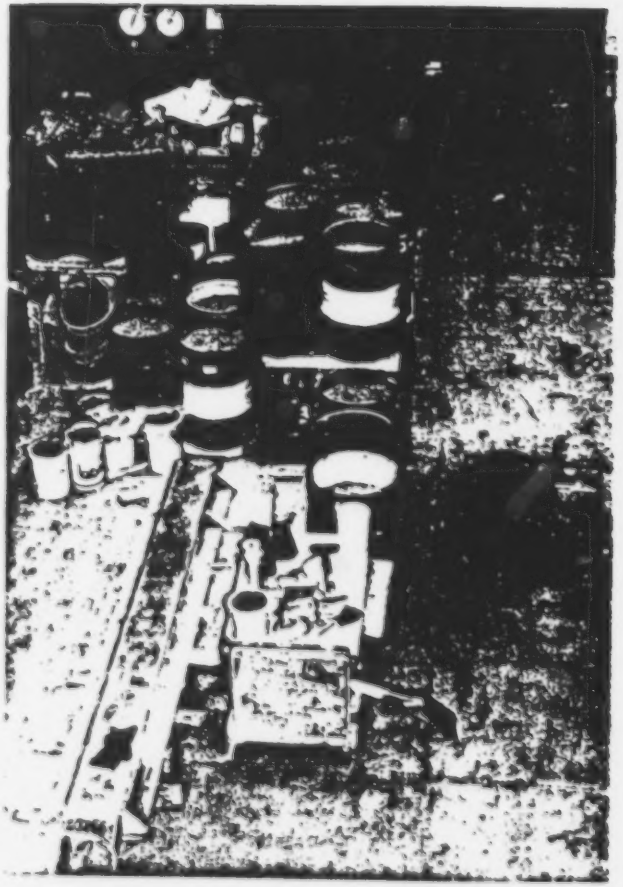
PERFORMANCE OF CONCRETE PANELS
EXPOSED TO ICE ABRASION AT
NANISIVIK, BAFFIN ISLAND

(DSS File No. 03SQ.23440-6-9003)

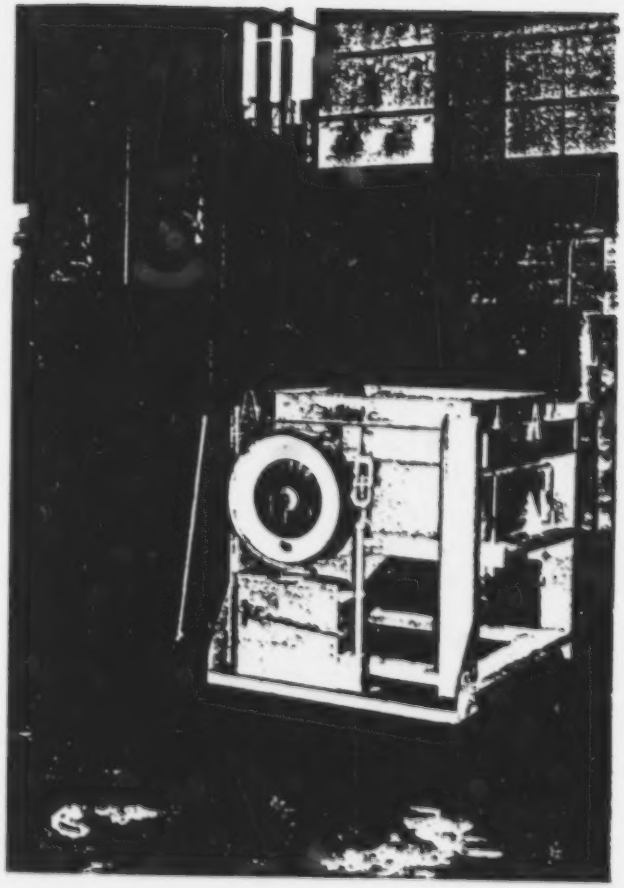


23pp

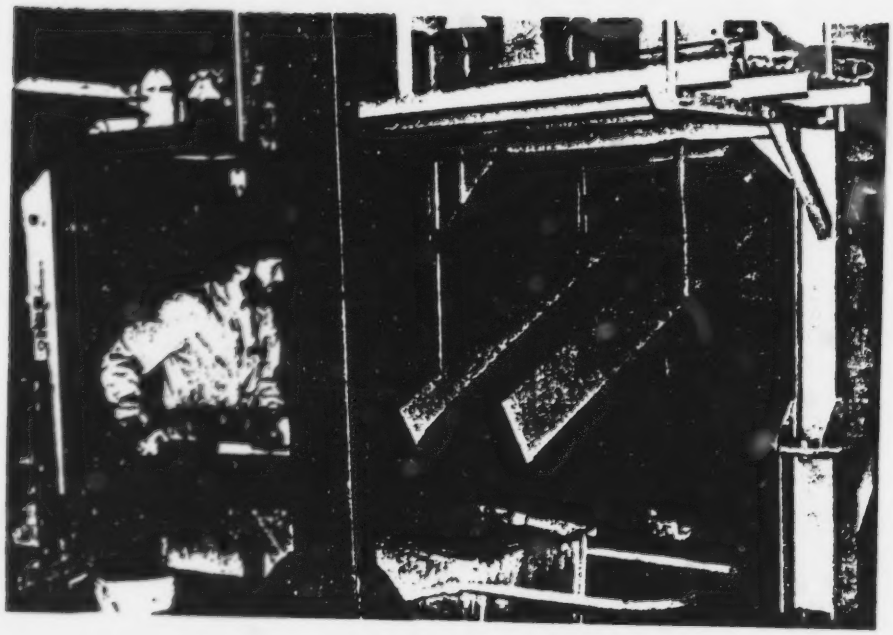
MICROMEDIA



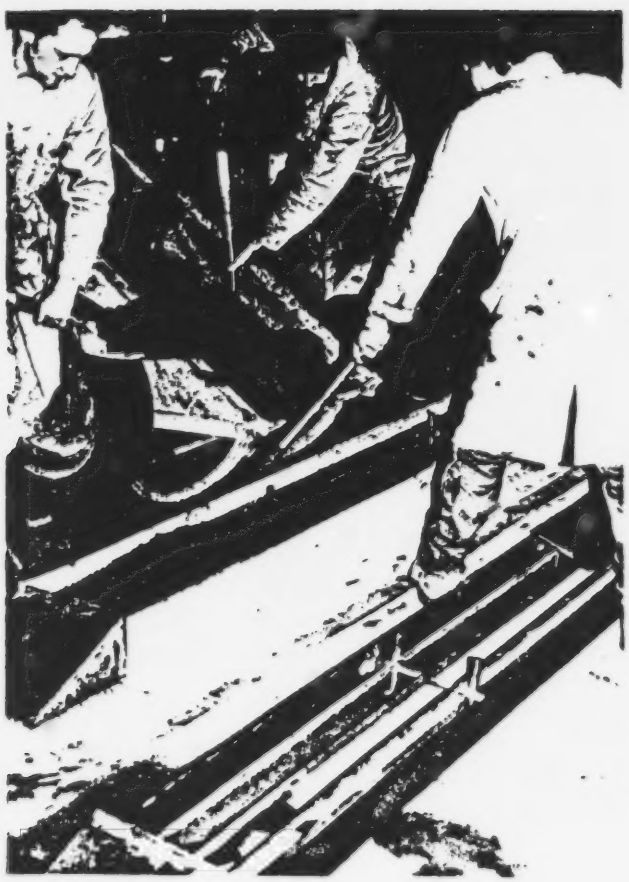
Stockpiled concreting materials; sampling and testing equipment; concrete test panels after casting.



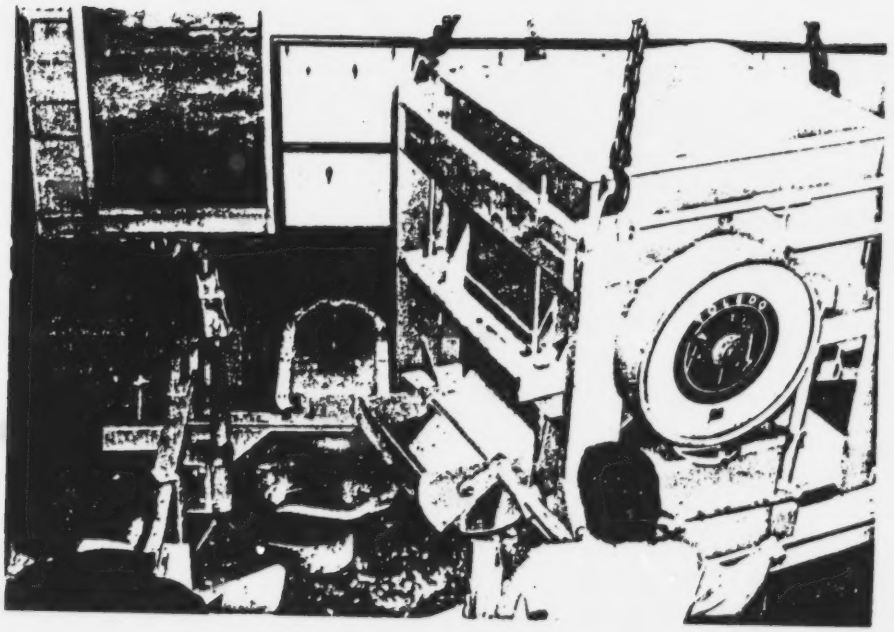
Foreground: aggregate weigh hopper and scale; Background: platform-mounted turbine mixer.



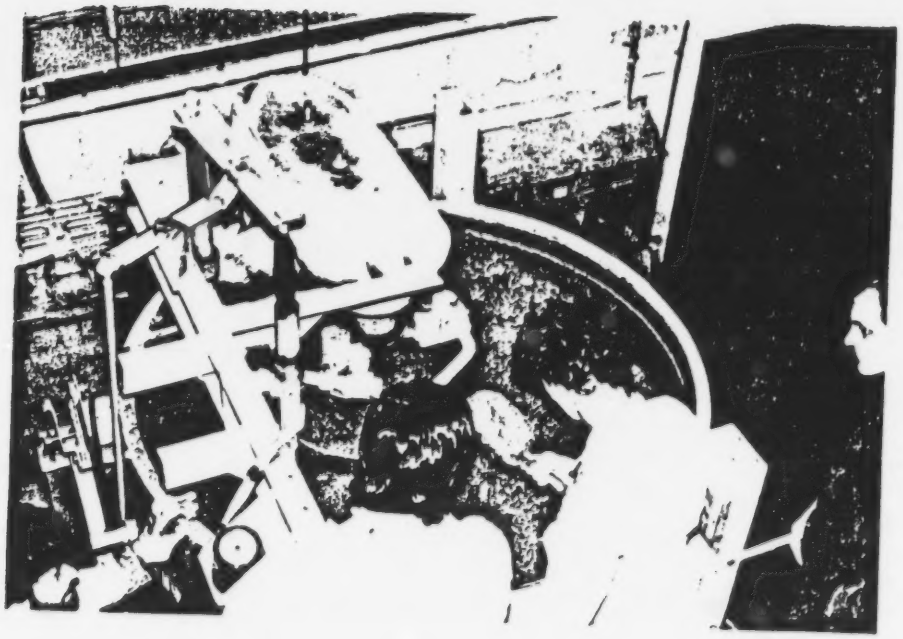
Loading rubber-tired buggies
from mixer.



Casting test panel.

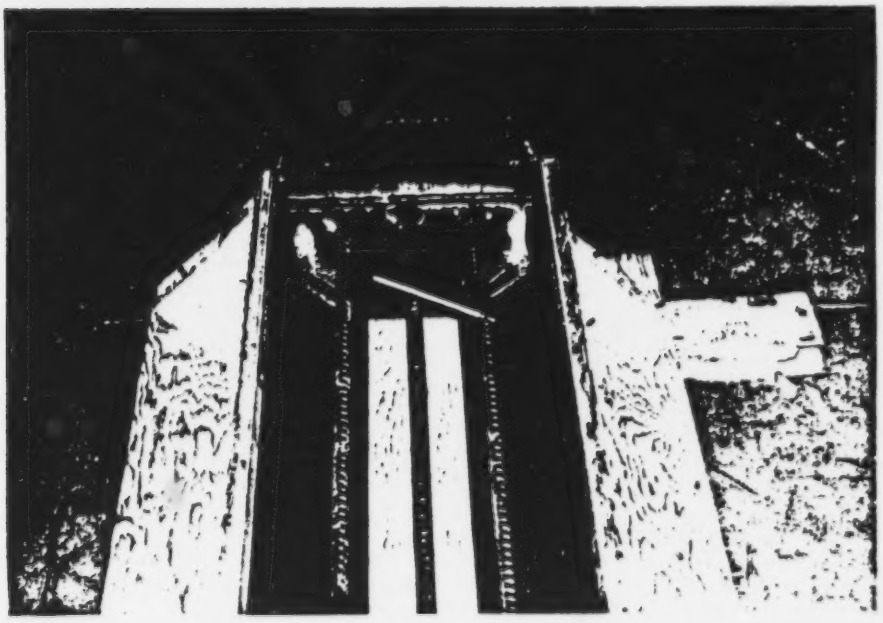


Discharging weighed aggregates into revolving mixer.



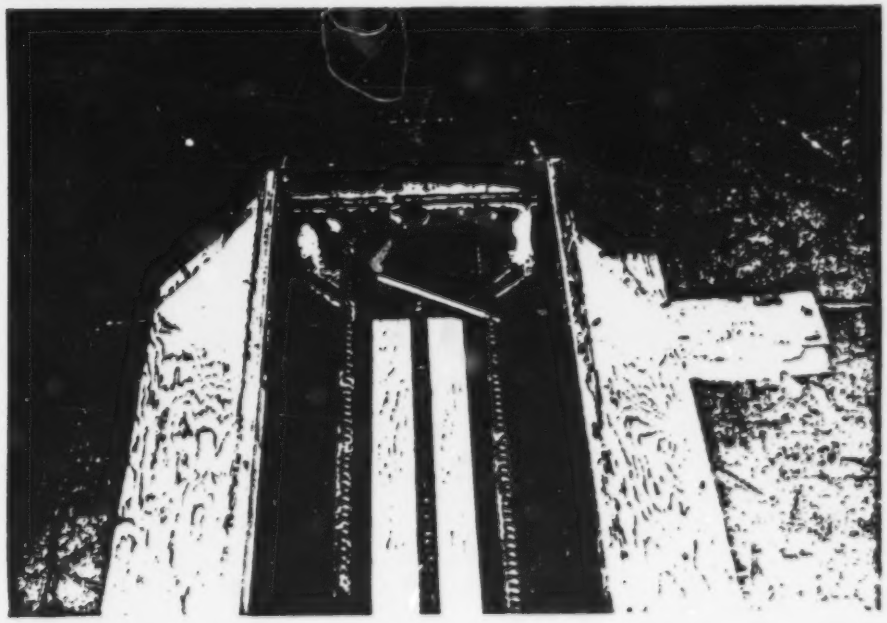
Checking the mix visually (note stop-watch in left foreground).

Test panel frames before and after construction of wood forms.
Note vertical stainless steel datum pins installed at third-points.

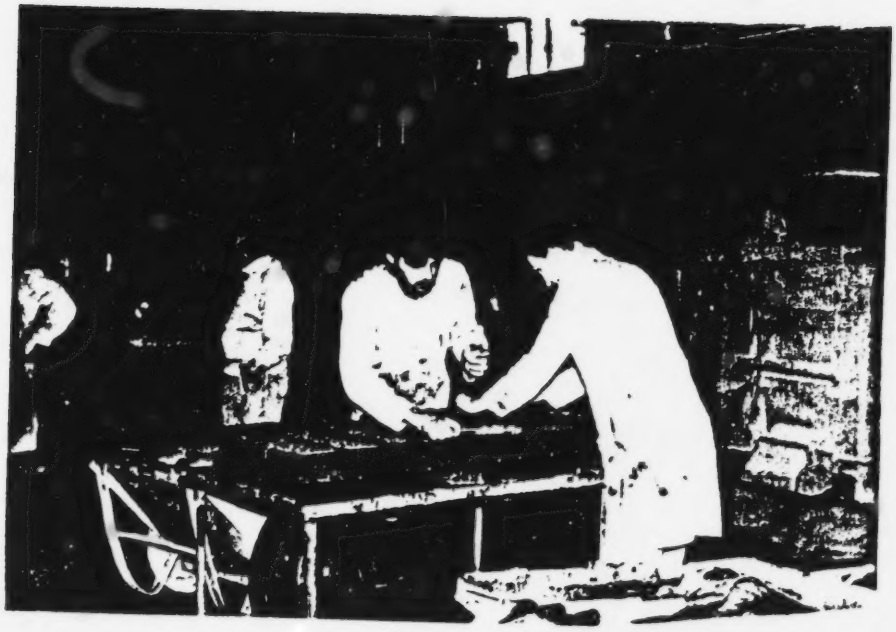


End detail of test panel frame and form. Note reinforcement welded to protective triangular steel box.

Test panel frames before and after construction of wood forms.
Note vertical stainless steel datum pins installed at third-points.



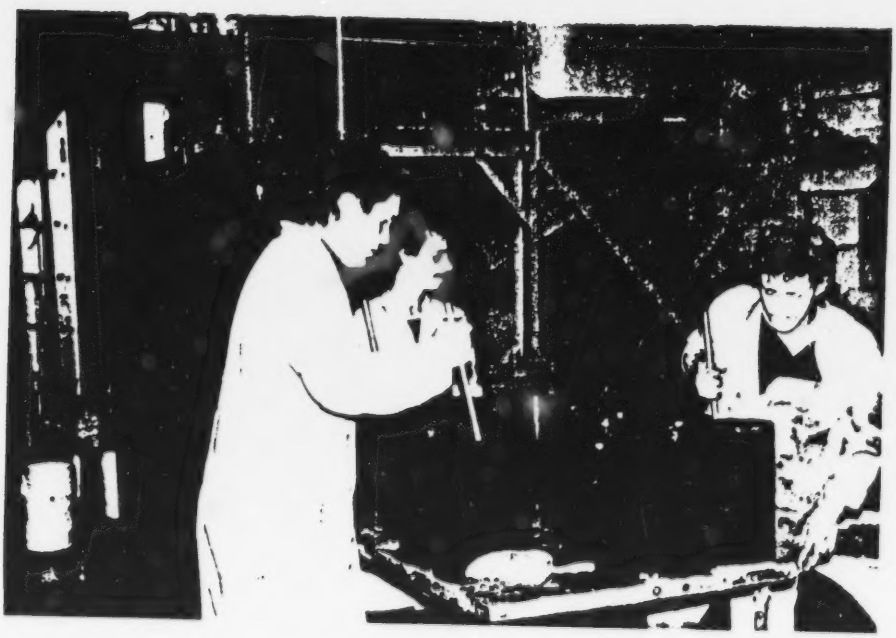
End detail of test panel frame and form. Note reinforcement welded to protective triangular steel box.



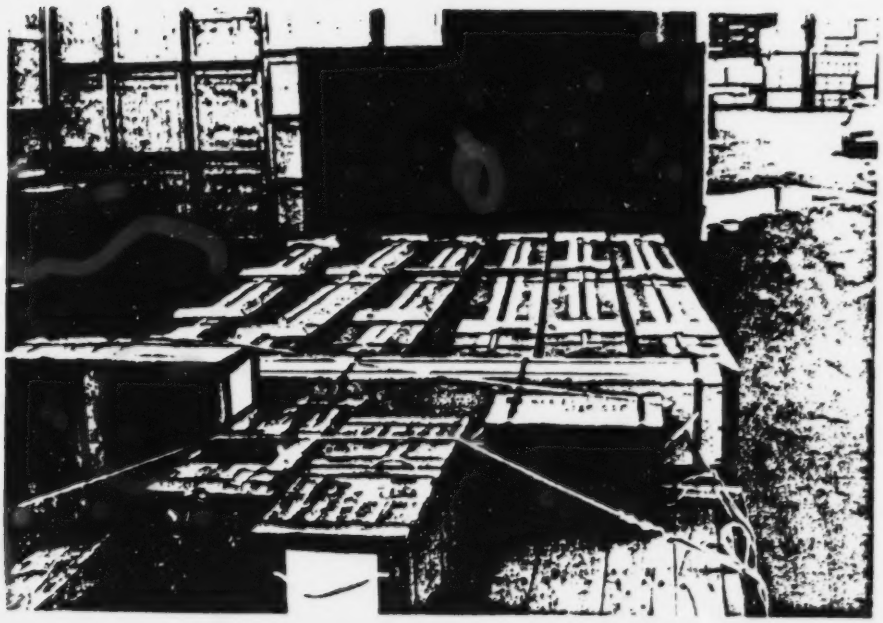
Casting samples for
flexural strength tests

Stockpiling test panels for
laboratory air-dried curing.

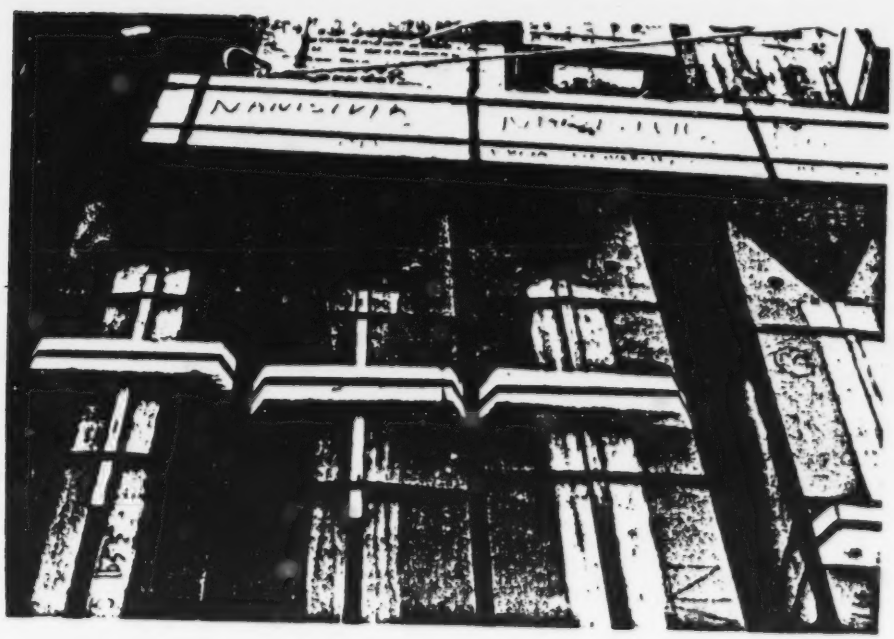
Final compacting pass of vibrator and surface finishing of panel.



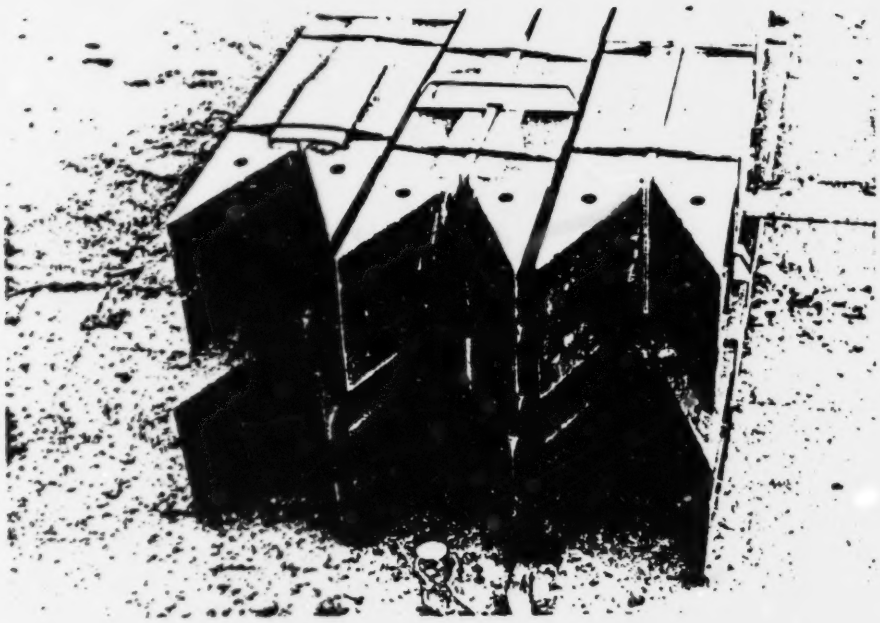
Casting of samples for compressive strength tests.



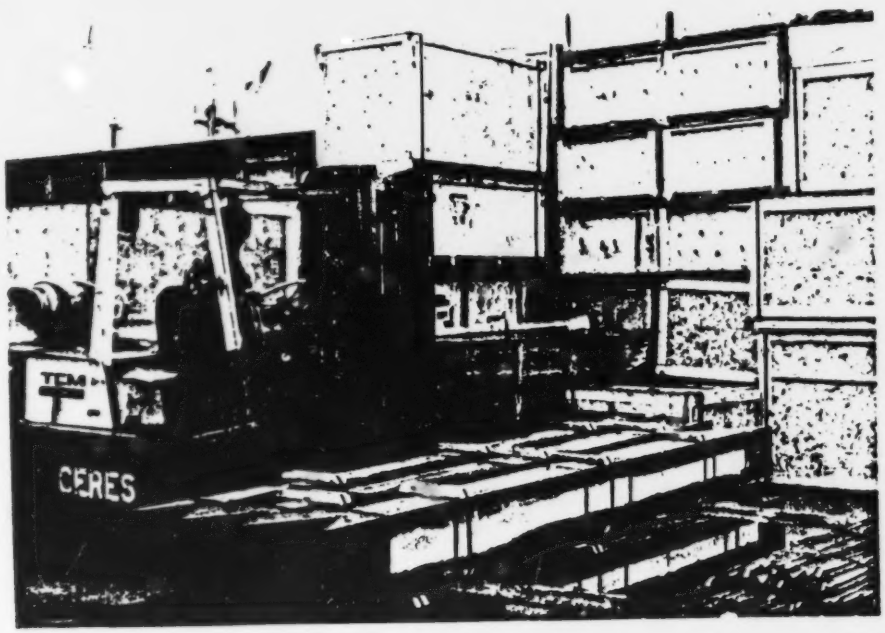
Test panels and accessory laboratory equipment on flatbed truck, as transported from University to Crosby Shipping, Port of Montreal.



Close-up showing lumber protection secured by steel strapping. Paired panels mounted face-to-face to prevent damage to concrete surfaces and edges.



Close-up showing identifying weld numbers at panel ends.



Forklift truck stockpiling panels at dockside storage area, Port of Montreal.

Manisivik Dock: View from shoreline, August 11, 1986.

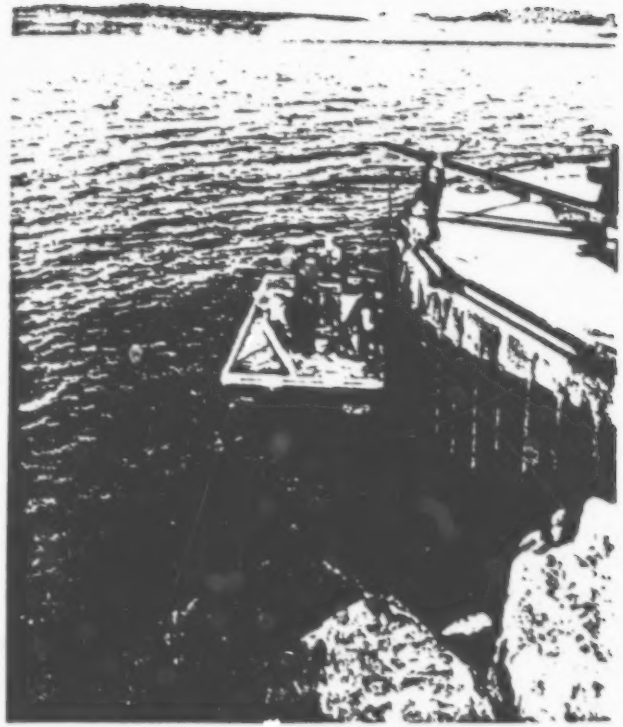
Strathcona Sound: View to West and open sea, from shore near dock.

Stockpiled test panels
at Nanisivik dock.

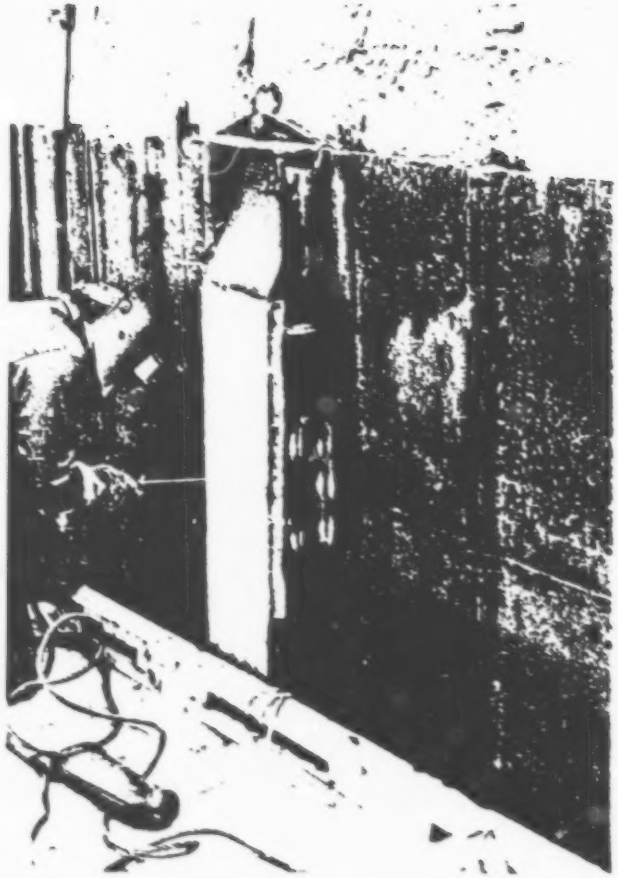
Using bulldozer-boom,
cable sling and yoke
for handling of panel.

Floating work-platform used for installation of panels.

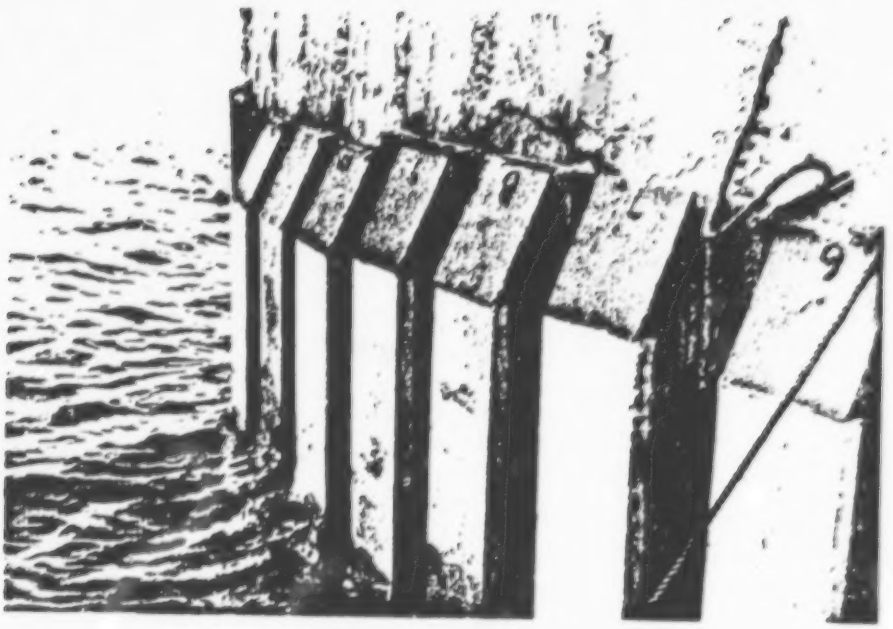
Lowering concrete panel into position.



View of installation from shoreline

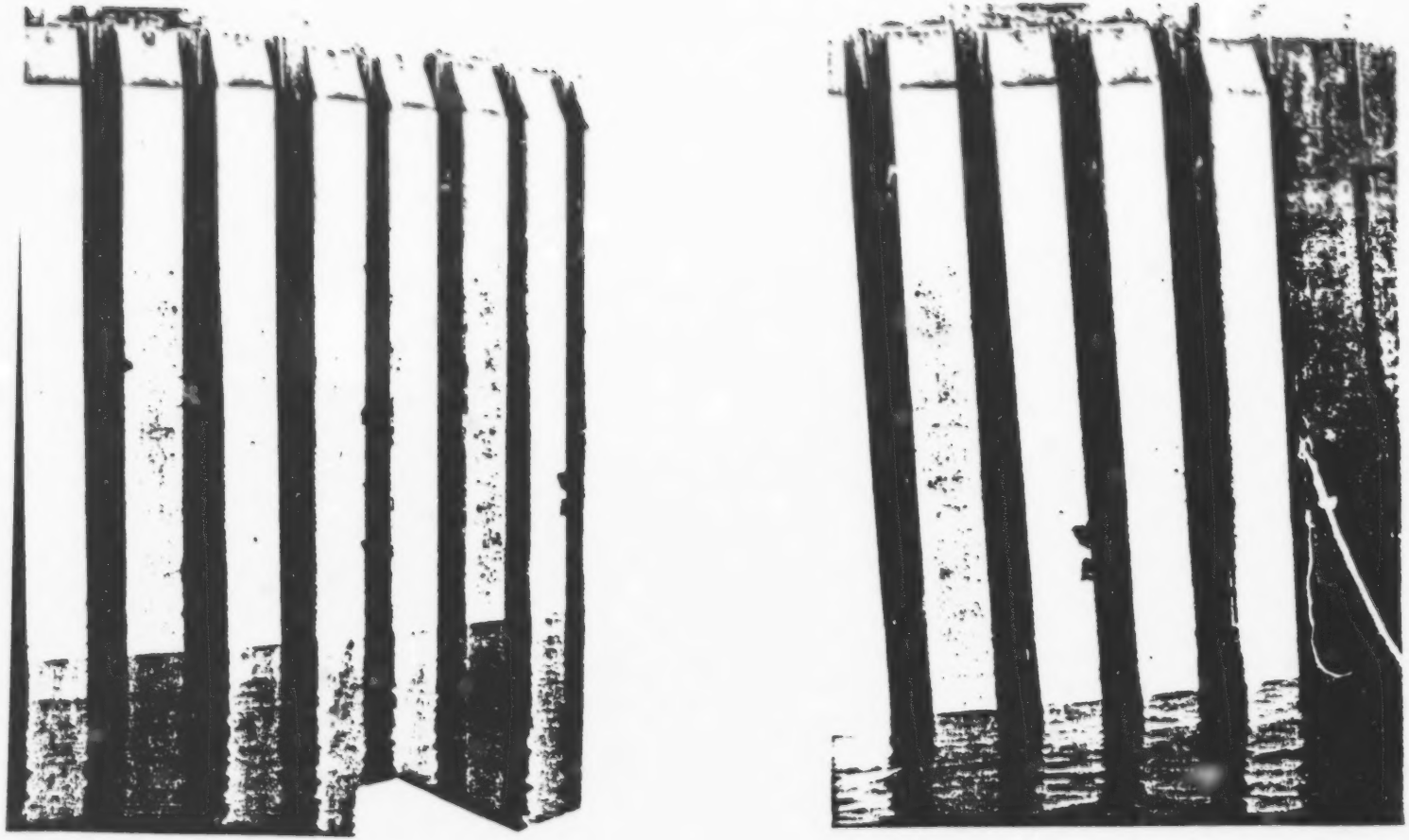


Tack-welding using 12" x 3" x 5/8" plates.

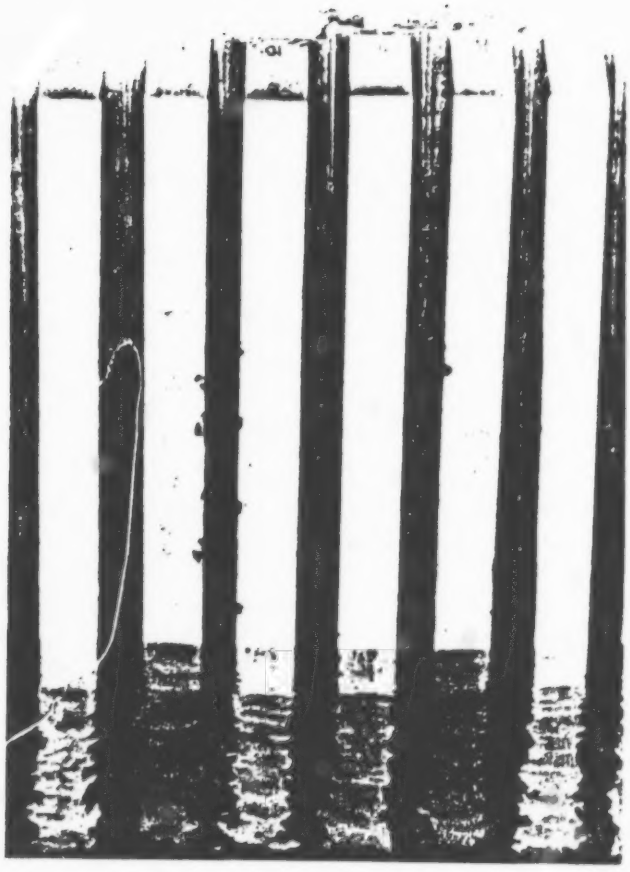


Panels Nos. 6 to 12, at high tide, August, 1986.

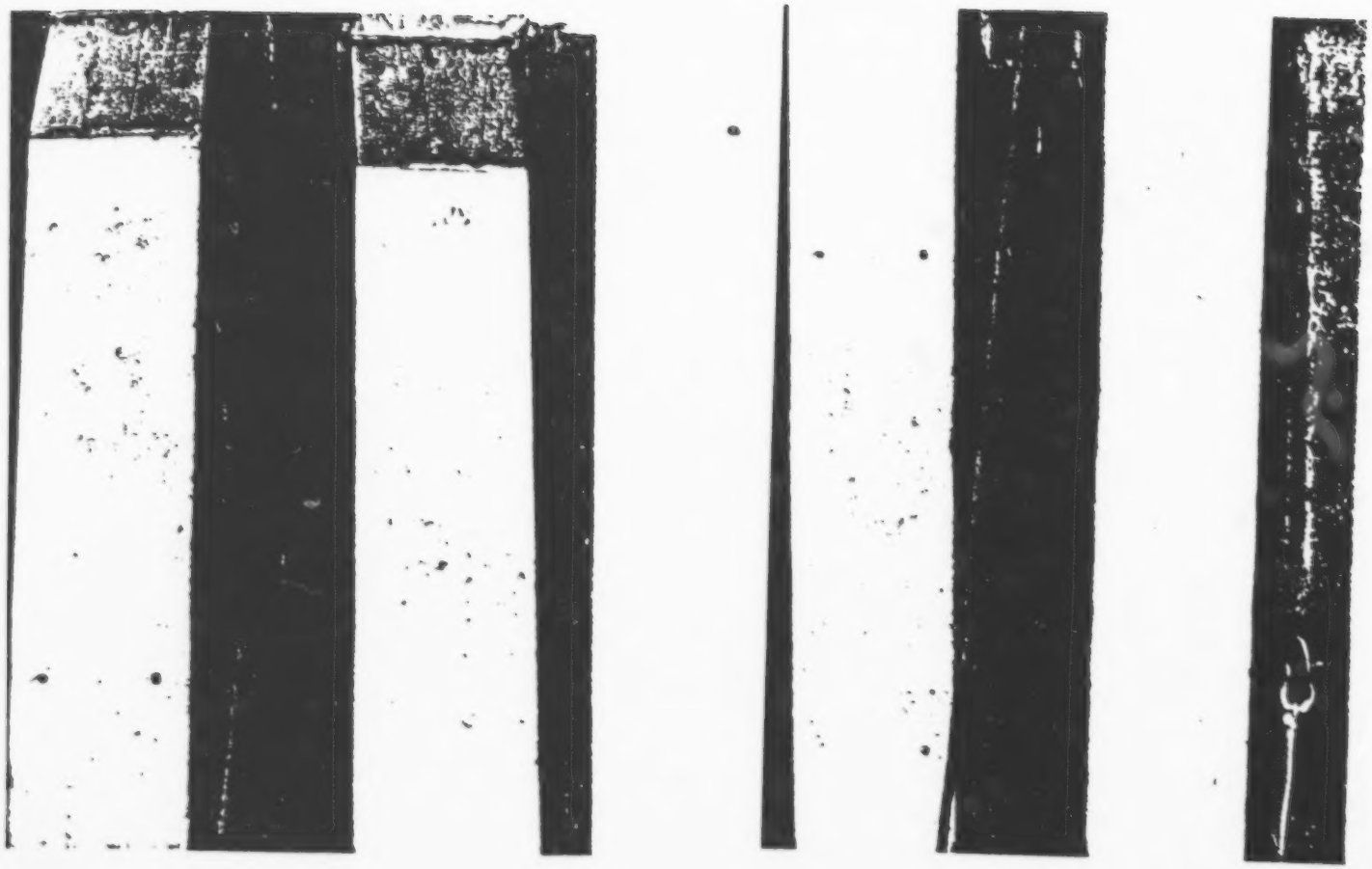
Close-up of 5/8" steel plate welded in position.



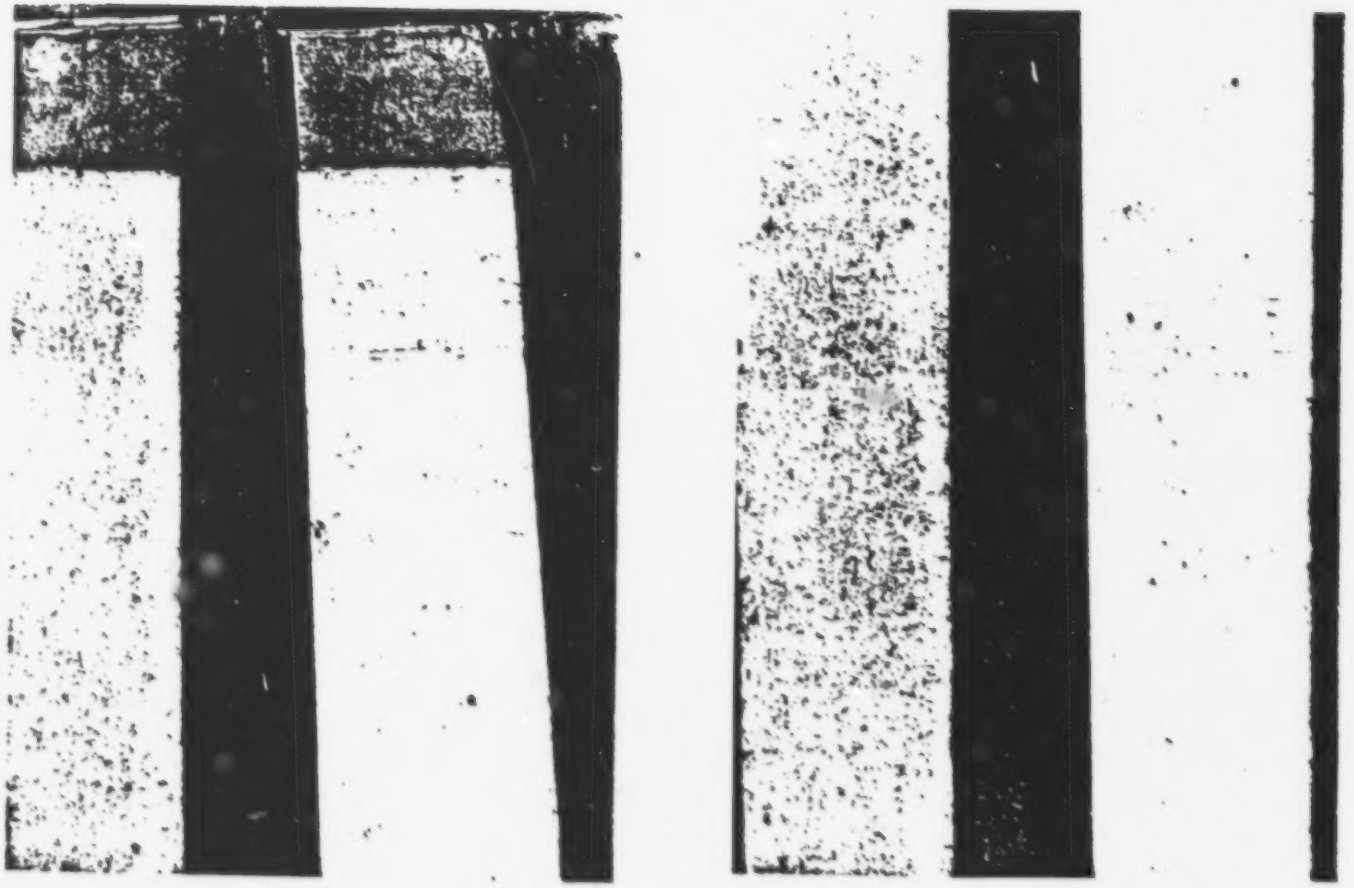
Panels Nos. 1 to 4 and 3 to 9, at low tide, August, 1986.



Panels Nos. 7 to 12, at low tide, August, 1986.



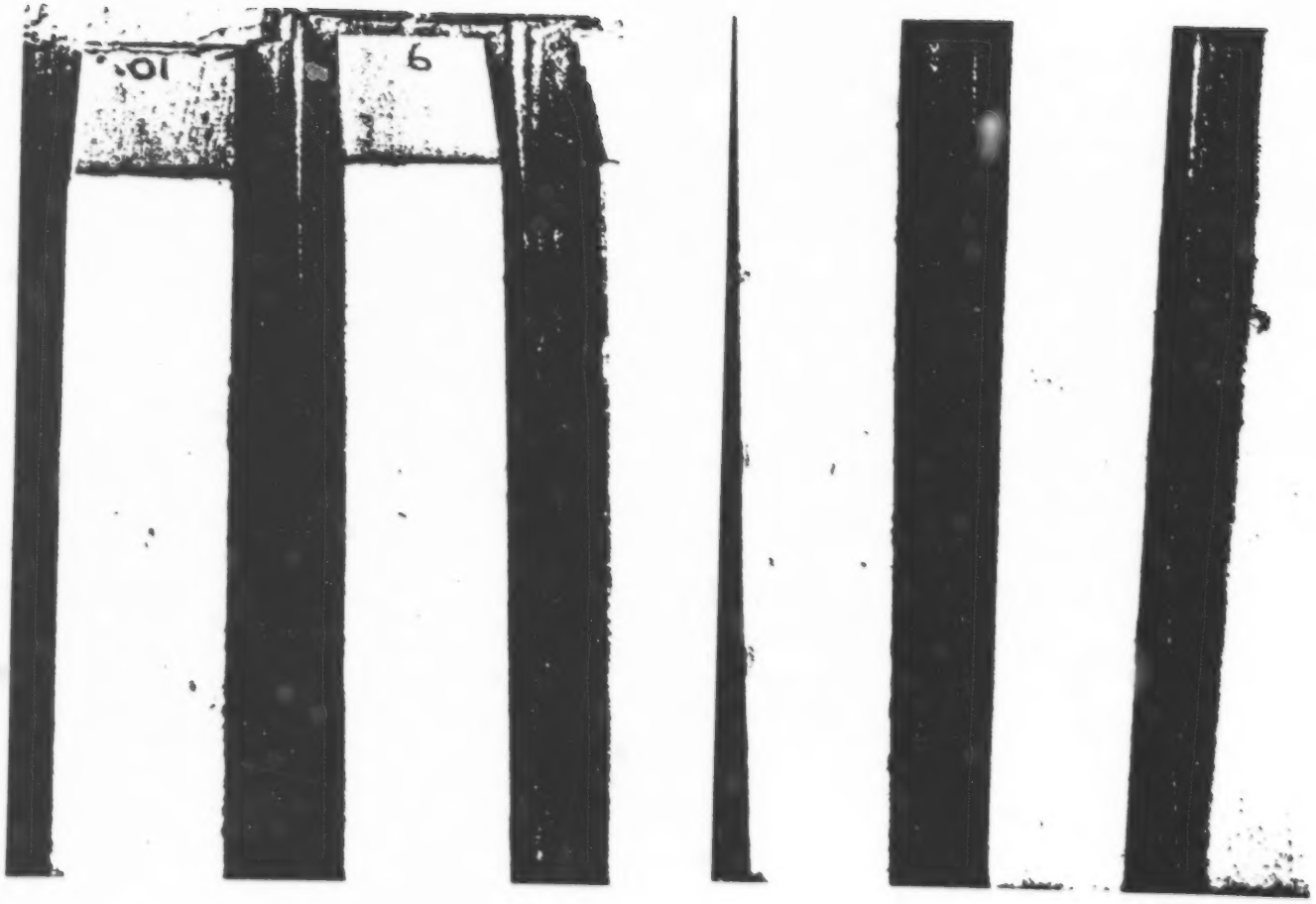
Close-up views of Panels 1 and 2, at low tide, August 11, 1986.



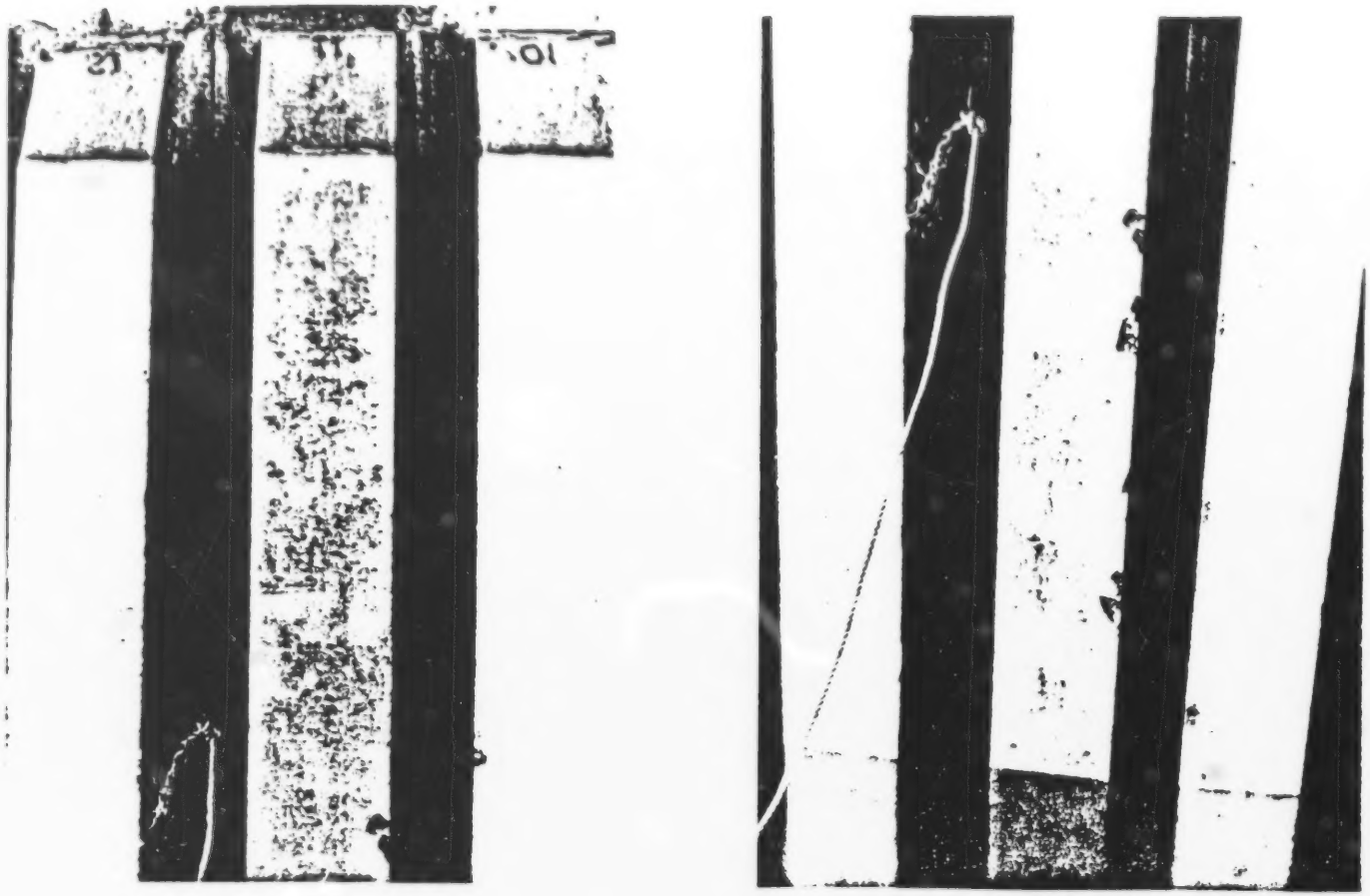
Close-up views of Panels 3 and 4, at low tide, August 11, 1986.

Close-up views of Panels 5 and 6, at low tide, August 11, 1986.

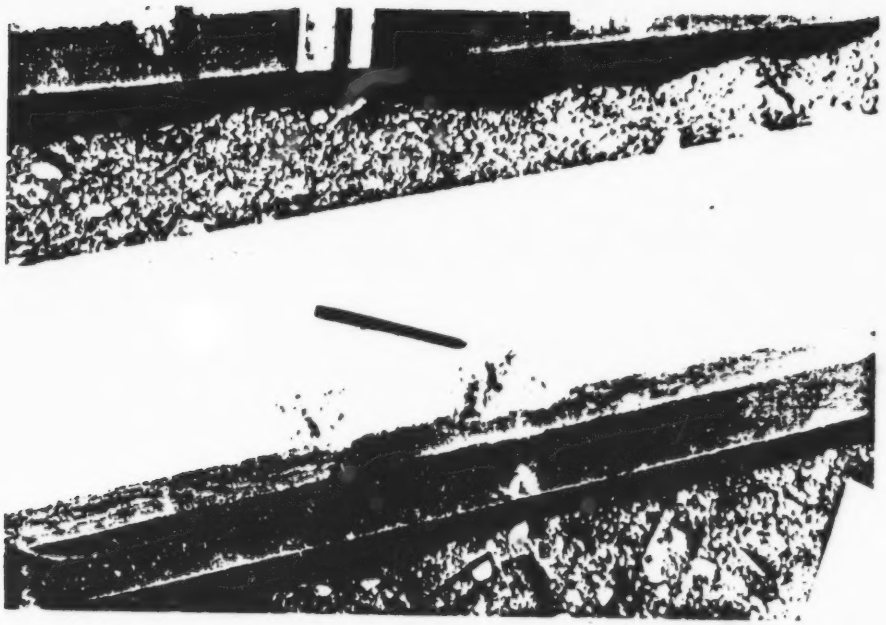
Close-up views of Panels 7 and 8, at low tide, August 11, 1986.



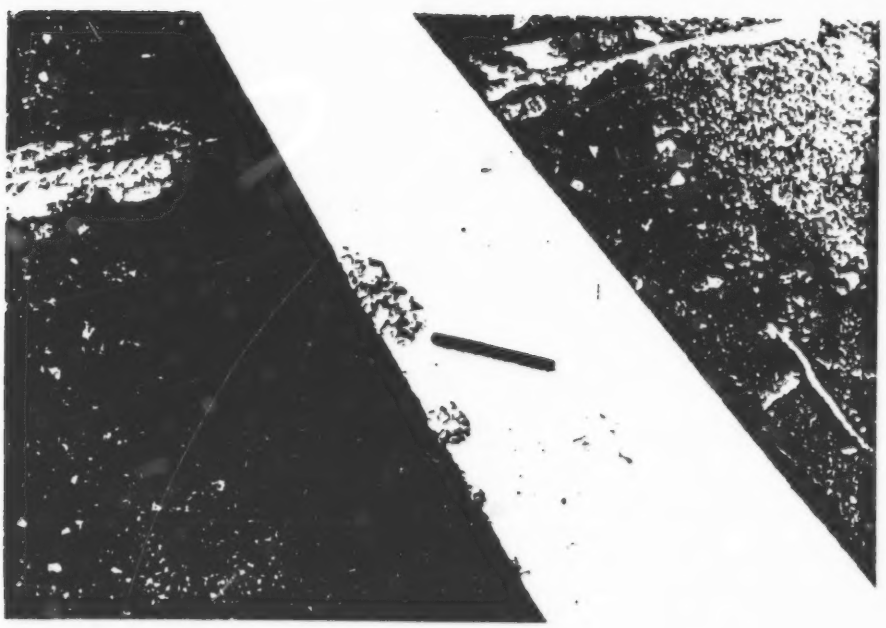
Close-up views of Panels 9 and 10, at low tide, August 11, 1986.



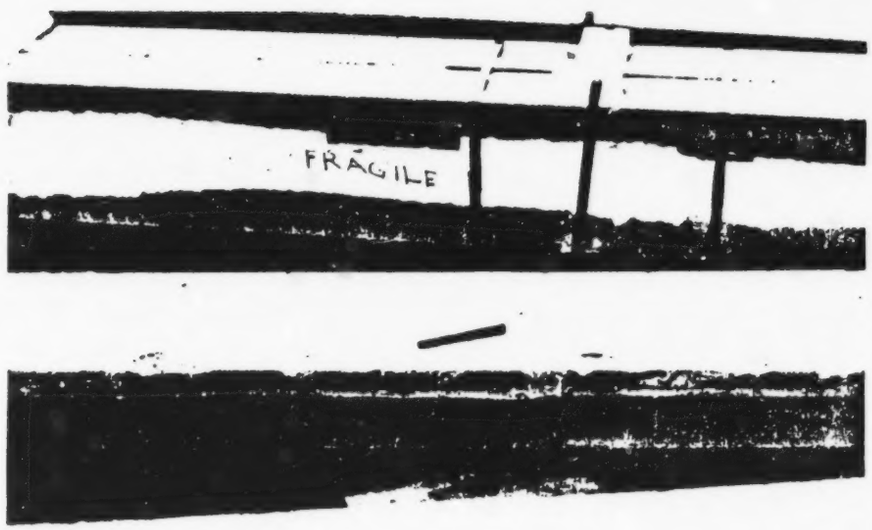
Close-up views of Panels 10, 11 and 12, at low tide, August 11, 1986.



Damaged surface of Panel No. 3, prior to installation.



Damaged surface of Panel No. 5, prior to installation.



Damaged surface of Panel No. 11, prior to installation.